PETROLEUM DEVELOPMENT AND TECHNOLOGY in 1927

PETROLEUM DIVISION

A. I. M. E.

PETROLEUM DEVELOPMENT AND TECHNOLOGY IN 1927

PETROLEUM DIVISION
A. I. M. E.

PAPERS PRESENTED BEFORE THE DIVISION, AT FORT WORTH, TEXAS, OCT. 19–20, 1927, AND NEW YORK, FEB. 20–23, 1928

PUBLISHED BY
THE AMERICAN INSTITUTE OF
MINING AND METALLURGICAL ENGINEERS, Inc.
29 WEST 39TH STREET. NEW YORK CITY

PRINTED IN THE UNITED STATES OF AMERICA

THE MAPLE PRESS COMPANY, YORK, PA.

CONTENTS

Production

Petroleum Economics

Engineering Education

LETTER OF TRANSMITTAL

H. Foster Bain, Secretary,
American Institute of Mining and Metallurgical Engineers,
29 West 39th Street,
New York, N. Y.

Dear Sir:

I take pleasure in transmitting herewith "Petroleum Development and Technology in 1927," in which we have attempted to set out in a series of 40 papers with attendant discussions the advances made in Production Engineering and Refinery Engineering during the year. The volume also contains a digest of round table discussions on Petroleum Engineering Research problems and Petroleum Engineering Education. In addition to the above we set out in 16 papers a review of production of each producing area of the United States and of the more important foreign countries, together with a review of the world's production and forecasts for 1928. We also include 8 papers on the Economics of the oil industry.

The papers and discussions included herein represent the contributions of more than 200 engineers, including the foremost in each line. These papers were presented at technical sessions held in Fort Worth in October, 1927, and at the annual meeting in New York in February, 1928. We desire to express our thanks and appreciation to all those who have contributed to this volume.

As in previous years, we have attempted to emphasize the value of both written and impromptu discussions. We have made a practice of returning all impromptu discussions to the authors for correction and amplification, and because of this practice we feel that the discussions contained herein are in very presentable and readable form.

It was decided by the nominating committee when meeting for the purpose of nominating officers for 1928 to eliminate the vice-chairmanship for Transportation Engineering, as that branch of the industry seemed to come more naturally under the activities of the American Petroleum Institute. It was also decided by this committee to institute a new vice-chairmanship for Petroleum Engineering Research. We have had heretofore round table discussions on engineering research, but through the newly created vice-chairmanship, to which Mr. L. C. Uren was elected, we expect to have more comprehensive sessions on engineering research than heretofore.

We feel that the papers and discussions covering the developments of petroleum engineering during 1927 represent a real contribution to the industry. Considering the large number of important contributions, it is difficult to single out particular papers, but special mention may be made of the paper by Pierce and Lewis, "Principles Underlying the Air-gas Lift." Special mention should also be made of Mr. Zavoico's paper on "The Oil Fields of Russia," and of "Oil and Gas Resources of Kansas in 1927," by Mr. Kesler. Unfortunately these last two papers could not be published in full in this volume. The high quality of the papers on Refinery Engineering should also be commended. Special attention is called to Mr. Pogue's paper, "The Trend of the Petroleum Situation," which gives a most illuminating picture of the economic conditions.

I wish here to express my personal appreciation to those who have worked so unselfishly and conscientiously during the past year in order to make this volume truly representative of the developments of petroleum technology during the year: Mr. J. B. Umpleby, who planned all sessions on Petroleum Engineering; Mr. Walter Miller, vice-chairman for Refinery Engineering; Mr. J. E. Pogue, who arranged for the papers on Economics; Mr. W. E. Wrather, for his work on the Production symposium; Mr. Harry H. Hill, who led the round table discussion on Engineering Research; Mr. H. C. George, who conducted the discussion on Petroleum Educational Problems; and Mr. E. O. Bennett and Mr. A. C. Rubel, in the capacity of associate vice-chairmen of Production Engineering. Thanks are due the officers of the Institute and the editorial staff.

We feel that the Petroleum Division during 1927 has advanced in its capacity as a forum for technical discussion for the oil industry, and that under the leadership of the group of capable officers elected for 1928 the Petroleum Division will continue to give its service to the oil industry, and in perhaps a broader manner than heretofore.

Respectfully submitted,

John M. Lovejoy,

Chairman, Petroleum Division for 1927.

PLANS OF PETROLEUM DIVISION FOR 1928

H. Foster Bain, Secretary,
American Institute of Mining and Metallurgical Engineers,
29 West 39th Street,
New York, N. Y.

Dear Sir:

The present plans for the Petroleum Division of the American Institute of Mining and Metallurgical Engineers provide for two principal meetings in the year 1928. The first will be at Tulsa, Okla., in September or October, 1928, with the exact date largely dependent upon the date of the International Petroleum Exposition. The officers wish to hold the meeting at the same time as the Exposition in order that members of the Petroleum Division of the A. I. M. E. may have the advantage of attending both meetings at the same time. It is planned that this meeting will be devoted largely to petroleum production engineering problems. A tentative outline of subjects to be discussed is as follows:

1. Repressuring New Oil Fields, and naturally in conjunction with this falls Repressuring of Old Fields.
2. Air or Gas Lift.
3. Flow Strings in New Wells.
4. Deep Drilling Technique.

It is also planned to have at this meeting a general paper relating to Supply and Demand of Petroleum and its Products.

The second meeting is planned for February, 1929, in New York at the same time as the annual meeting of the Institute. Special details have not been carried very far on this meeting, although it is expected the program will cover technical problems in relation to production and refining of crude oil, as well as 1928 development in foreign fields and the United States.

It is planned during 1928 to cooperate with the Bureau of Mines in an attempt to compile a set of definitions on petroleum engineering. These would be of value to the petroleum engineering profession, in order to better standardize various terms used in discussion of current problems.

It has also been suggested that the Petroleum Division study certain problems in which research work is needed by the petroleum industry and outline certain definite programs that could be carried out by the Bureau of Mines and the U. S. Geological Survey, as a follow-up to

resolutions which have been passed endorsing the general idea that Congress provide the Bureau of Mines and the U. S. Geological Survey with additional funds. It is felt that there is better chance to obtain the funds when specific problems are outlined and the need for such information presented.

It is planned to cooperate closely with the Local Sections and at this time it appears some very interesting group meetings will be held to discuss problems of immediate interest.

Respectfully submitted,

A. W. Ambrose,

Chairman, Petroleum Division for 1928.

A. I. M. E. OFFICERS AND DIRECTORS

For the year ending February, 1929

President, George Otis Smith, Washington, D. C.
Past President, Samuel A. Taylor, Pittsburgh, Pa.
Past President, E. DeGolyer, New York, N. Y.
First Vice-president, W. H. Bassett, Waterbury, Conn.
Treasurer, Karl Eilers, New York, N. Y.
Secretary, H. Foster Bain, New York, N. Y.
Assistant Secretary, Thomas T. Read, New York, N. Y.

Vice-presidents

Birch O. Mahaffey, St. Louis, Mo.
Carl A. Meissner, New York, N. Y.
Henry Krumb, Salt Lake City, Utah.
F. Julius Fohs, New York, N. Y.
W. H. Bassett, Waterbury, Conn.
George D. Barron, New York, N. Y.

Directors

L. K. Armstrong, Spokane, Wash.
H. A. Guess, New York, N. Y.
W. Spencer Hutchinson, Cambridge, Mass.
Harvey S. Mudd, Los Angeles, Cal.
Reno H. Sales, Butte, Mont.
Frank H. Crockard, Woodward, Ala.
J. O. Elton, Salt Lake City, Utah.
Daniel C. Jackling, San Francisco, Cal.
David Levinger, Chicago, Ill.
Richard Peters, Jr., Philadelphia, Pa.
Herman C. Bellinger, New York, N. Y.
Karl Eilers, New York, N. Y.
H. G. Moulton, New York, N. Y.
J. V. W. Reynders, New York, N. Y.
Robert E. Tally, Jerome, Ariz.

Counsel, Douglas, Armitage and McCann, New York, N. Y.

Officers of the Petroleum Division

A. W. Ambrose, Chairman, Manager of production, Empire Companies, Bartlesville, Okla.

C. R. McCollom, Associate Chairman. Petroleum geologist, Los Angeles, Cal.

H. W. Camp, Vice-chairman, Refinery Engineering. General superintendent, Empire Oil & Refining Co., Tulsa, Okla.

E. O. Bennett, Vice-chairman, Production Engineering. Petroleum engineer, production department, Marland Oil Co. of Oklahoma, Ponca City, Okla.

C. V. Millikan, Associate Vice-chairman, Production Engineering. Petroleum engineer, Amerada Petroleum Corpn., Tulsa, Okla.

Joseph Jensen, Vice-chairman, Production. Geologist, Associated Oil Co., San Francisco, Cal.

Lester C. Uren, Vice-chairman, Research Engineering. Professor of petroleum engineering, University of California, Berkeley, Cal.

Arthur Knapp, Vice-chairman, Economics. Petroleum engineer, The United Gas Improvement Co., Philadelphia, Pa.

Production Engineering

Production Engineering in 1927

By J. B. Umpleby,* Oklahoma City, Okla.

(New York Meeting, February, 1928)

Production engineering in 1927 may be characterized by a great clarification of fundamental conceptions, and many improvements in technique. During the year the profession has received marked recognition by the industry and to an extent never before attained has become an integral part of it.

History

Petroleum production engineering is a new profession. Prior to 1925, when this Institute undertook the work, no forum existed for the open discussion of its technical problems. There was no attempt at a handbook of the subject prior to "Petroleum Production Methods" by J. R. Suman, in 1921, and no textbook prior to "Petroleum Production Engineering" by L. C. Uren, in 1924. As late as 1926, only six schools and universities offered special courses in petroleum production engineering. Prior to about 1923, engineers engaged by oil companies were used almost exclusively for construction and location work. Two of the leading production engineers in the Mid-Continent field, although with their respective companies more than twelve years, were not definitely assigned to production work until 1924. Both men now head large departments giving almost their entire time to production problems.

Because of the newness of the profession, the leading production engineers of today have had their fundamental training in mining, civil, mechanical and electrical courses. Not unlikely this diversified training is in considerable part responsible for the amazing growth of the profession. I believe, however, that recognition is due principally to economic pressure within the industry which has directed attention more and more sharply on costs and efficiency. After all, the justification for the growth and continued development of the profession is to recover more oil from a given unit of sand at less cost per barrel. In this new profession, it seems to me that greatest progress will result from focusing thought and effort on this single objective, and if I might offer one suggestion to the com-

* Chairman, Production Engineering, Petroleum Division A. I. M. E.

mittee for 1928 it would be to get more cost data into the records than my committee has done.

A crying need exists for a handbook combining data pertinent to our work. Who has not searched from the Smithsonian Physical Tables through the various engineering handbooks to the supply-house catalogs for some necessary data? I am not sure that if members of this organization gave it their support it would not be possible to get the Petroleum Division of the American Petroleum Institute to undertake this task. The first edition might be prepared in a stated time, frankly admitting incompleteness and counting on later editions and criticisms to attain the objective. It might be possible, if properly presented, also to get a part of the funds available for fundamental research in petroleum physics directed to a determination of formulas greatly needed in air-gas lift and gas-energy studies. Surely the determination of reliable constants that may be used over and over again may be classed as fundamental research.

Recognition of the Engineer

The recognition of the petroleum engineer is well shown by the hearty approval of the work of the Standardization Committee of the A. P. I. I understand that in the equipment phase of this work no recommendations were adopted without the critical study and approval of the engineering subcommittee; that the engineers drafted most of the specifications and otherwise contributed largely to the success of the undertaking. The committee organization was ideal for results, consisting of the operating man, the supply man and the engineer with the operating man in charge.

Recognition was also accorded the engineer in the creation of a Petroleum Engineering Division of the A. P. I., the invitation extended the engineers to contribute to the gas-conservation studies under the direction of the Committee of Seven headed by E. W. Marland; the several references to the engineers by E. W. Clark, President of the A. P. I., in his annual address to the Institute; the direct credit given the engineers for many improvements in oil-field practice and the increased employment of engineers by oil companies.

Problems Confronting the Industry

Most of the problems confronting the industry have engineering phases. Among the live issues at present are waste, unit operation, utilization of gas energy, well spacing, repressuring, and the great urgency for more temperate expenditures throughout the production and marketing phases to this end that costs may be reduced.

Waste

Press and technical journals contain many assertions and denials that there is waste in the oil industry. Both contentions have merit,

depending on the definition of waste. Incident to physical operation there is remarkably little waste, but from the standpoint of economic control there is tremendous waste. The loss of fluid from the time a natural reservoir is tapped to the point of delivery of gasoline to the tourist or coke to the householder is remarkably small. The economic losses incident to excessive competition are excessively high. The oil industry supports too many people. Consider the number of filling stations, the number of lease brokers, scouts and branch offices, the number of drilling contractors, casing crews, teaming contractors and rig builders, mostly part-time employees. If employment were steady, probably half the number could do all the work at half the cost. The reason for this is too much and too keen competition. The idea that competition necessarily reduces cost to the consumer is, under certain conditions, a fallacy. In the oil industry at present it greatly increases cost, which is passed on to the consumer. This, however, may be only incidental to a corrective phase. We are witnessing a movement toward less competition which itself may later induce excessive competition, and so on in waves of decreasing amplitude until a condition is reached that is fair to both producer and consumer.

Excessive competition finds expression in too rapid development of new fields; a disregard of the broader requirements of the industry at a particular time; too many filling stations; too many refineries; in many cases too close spacing of wells; development under unnecessarily adverse conditions of transportation; unnecessary employment of inefficient labor; too large a rental and bonus cost on protection acreage; too much storage on top of the ground instead of reserves in the sand; and, probably more important than all from the standpoint of conservation, failure to use to a maximum in producing oil the gas energy that accompanies it in nature.

Thus economic waste in the oil industry is tremendous, although resource waste may be negligible. Waste lies chiefly in the fields of competitive finding and acquisition, competitive development and competitive marketing.

Most costly of these is probably competitive development, and as this is primarily the field of the production engineer he cannot refrain from taking interest in it; he cannot give too careful study to problems of well spacing, defensive drilling, utilization of gas energy, and the physical problems of unit operation.

Unit Operation

Unit operation has so many advantages in so many fields, both to the consumer and to the industry, that it or some equivalent is bound to come on an increasing scale even if revision of law is necessary to make it possible. Working out of details will involve largely information and

conclusions to be supplied by the production engineer and he should prepare himself in every way possible for the call. The engineer's part in a unit operation will probably be a continuing one because any contract must, from our present knowledge, leave wide discretion to the operating committee and many of its problems will involve engineering analysis.

Gas Energy

During the past year the conception of gas energy has displaced in large part the old conception of gas-oil ratio. It is erroneous to measure production efficiency by the volume of gas that accompanies a barrel of oil, because volume increases in effectiveness as an expellent of oil as pressure increases. The true measure of efficiency is the degree of effective utilization of energy stored in the reservoir; hence the new term, gas energy. If the relationship of gas energy consumed to oil produced is to be taken as the measure of operating efficiency, a vast field of research is opened. Clearly the amount of energy necessary to move a barrel of oil a given distance will vary with the character of the oil and reservoir rock. To get a measure of these several variables will require much fundamental research in the field of viscosity, oil composition, character, composition and size of sand grains and composition of gas in addition to pressure, volume and temperature determinations. I conceive, however, that the time will come when we can analyze bottom-hole data and compute for a particular situation the optimum of operating efficiency. Certainly the field is alluring and worthy of investigation. It seems to me that such work should properly be classed as fundamental research in physics.

The idea of conserving gas energy has led to notable achievements during the year. In the Ventura Avenue field in California, careful study of production and elimination of certain wells has effected a reduction said to be around 25 per cent. in gas blown into the air without seriously reducing production. This is a remarkable example of what can be done by coöperation in a closely drilled field of diversified ownership.

Well Spacing

Well spacing has received much attention during the year largely because many believe that wider spacing at Seminole would have yielded more profit without breaking the oil market. Well spacing is largely a matter of the balance sheet and it has been generally held that the closer wells are spaced the greater the recovery per acre. However, Prof. L. C. Uren has advanced a contrary view.[1] If his contention is correct it will have a revolutionizing effect on the industry. Uren contends that most of the gas energy is consumed in moving oil the last 10 ft. toward a hole because of the converging lines, hence faster rate of flow. He concludes:

---

[1] See page 146.

"Providing the wells are not spaced beyond the oil-drainage radius of each other, the fewer the number of wells used, the less rapidly will the oil be drained, and because of the lower average rate of flow of fluids through the sands, the energy consumption per barrel of oil produced will be lower. Hence, the ultimate recovery of oil will be greater for widely spaced wells than for closely spaced wells." His contention is supported by laboratory experiments which, although not fully convincing because of the limitations of the equipment, are highly suggestive and warrant much careful field observation, particularly where town-lot areas comprise parts of pools.

J. H. Gardner has pointed out the adverse relation between close spacing of wells and the balance sheet at Seminole, and T. B. Slick recommends developing one Wilcox pool on the basis of one well to 40 acres as an experiment.

To this may be added another thought. If the wells of the first generation throughout any pool are drilled on 40-acre locations production peaks will be lowered, storage-building program reduced and excessive costs due to rapid development averted. The greatest advantage, however, will result from a determination of the limits of the pool and the merits of its different parts. In places, such as parts of Hutchinson County, Texas, additional wells would not be drilled and in others such as Burbank, there would probably be a second generation of wells on 10-acre locations. In the former case the saving is obvious and in the latter case the fifth or central well would pay a profit as an intake for gas in the maintenance of pressure. This fifth well could be produced until the 10-acre locations were drilled. Time will not permit further development of this plan but I believe it can be worked out by agreement between lessees without doing injustice to the royalty owner, the small or large operator, and without justifying opposition by the Department of Justice or the State Conservation Commissions. It seems to have many of the advantages of unit ownership and to avoid many of the difficulties.

Repressuring

Repressuring, by the injection of air or gas into depleted sands, has not expanded in 1927 as it did during the two previous years. Periods of overproduction do not encourage this sort of activity. The idea of pressure maintenance, however, which might better be called energy maintenance, has received much attention. This has gone hand in hand with a clearer recognition of energy relationships in the sand. Energy may be maintained by maximum utilization in production and by injecting compressed gas or air through central wells; by not allowing gas to escape unduly at the front of the column and by adding it at the rear of the column. The injection of gas or air through central wells early in the development of a pool seems to be sound in theory and practice and will

undoubtedly come into much more general use. It is being done now with pressure up to 1800 lb. Closely related to it is the use of old fields and parts of fields as storage reservoirs for gas in order to avoid the construction of steel containers by gas-distributing companies. This is receiving serious attention in California and is being done successfully in the Osage.

Air-gas Lift

Turning from general problems to concrete accomplishments, the development and utilization of the air-gas lift in 1927 is outstanding. This method, known and used for more than a generation, came into prominence in handling deep production from crooked rotary holes in California in 1926. Its greatest development resulted from application in Seminole during 1927. At the beginning of the year, it was a try-and-fit method with few of its principles understood. At the close of the year many of the principles were known and the data necessary for the determination of others were clearly recognized. More important than this advance, however, is the fact that a large group of engineers and operators have become acquainted with the method, which insures its further use and development. Application is at present limited to larger wells because of the cost of installation but it is surprising what small wells can be handled profitably once the plant is in. In fact, some of our leading engineers believe there is no point at which it pays to take a deep well off the air and put it on the pump. Because of the excellent control of back-pressures afforded by the air-gas lift, reduction of the problems of well maintenance and its advantages over pumping in crooked holes, a wide expansion in its application seems to be imminent. Outstanding problems are corrosion incident to its use, simplification in design to afford lower cost, automatic controls for intermittent application, and a further knowledge of fundamentals to the end that specifications for any particular situation may be predetermined with greater assurance.

Closely parallel to the development of the air-gas lift has been an increased understanding of the significance of gas-oil ratios. The amount of gas accompanying a barrel of oil from any well gives an excellent measure of the comparative efficiency of operation from day to day of that particular well. However, in the light of our increased understanding of the relation of gas volume to gas energy and of gas energy to oil production, care should be exercised in measuring on this basis the relative efficiency of operation of different wells and more especially of different fields. In different pools and in different parts of the same pool maximum efficiency may be represented by widely different gas-oil ratios.

Drilling Equipment

Deeper drilling has led to many improvements in drilling equipment. Most of these have been in the direction of increased weight and strength

but much attention has been given also to reducing friction. Rotary drilling is being more widely employed and in many places rock bits are used from the grass roots down. An increasing number of wells are completed with rotary tools. The increased weight of equipment is shown by the common use of three 90-hp. boilers carrying 200 lb. of steam against two 45-hp. boilers carrying 120 lb. The compound slush pump, more careful selection of materials for rotary mud, automatic feeds, differential controls, better bits and coring devices and the introduction of roller and ball bearings in many parts of the equipment are noteworthy advances. There seems to be a tendency away from steam power to internal-combustion engines and electricity. Full Diesel, multiple-cylinder, vertical engines are now available in 125-hp. sizes. This movement is prompted by an urgent need to reduce fuel cost in drilling wells.

In the field of pumping wells the double-reduction gear unit and the long-stroke pump have become more common. The latter makes it possible to ease the shock at the end of the stroke and by less frequent changes in tension to reduce sucker-rod fatigue. It also compensates for the stretch in rods in very deep wells. The quality of material in sucker rods has been greatly improved and much study given to the best design for box and pins. Sucker-rod guides, either of wood or brass, as a means of reducing friction and protecting tubing have come into general use in some fields.

In operating shallow wells attention has been directed toward reducing the gas factor by raising tubing and by pressure-regulating valves on the gas-discharge line. The use of individual well powers in territory where electricity is available has increased. Some of these are placed between two wells in order to obtain the advantages of a counterbalance while doing useful work. The installation cost per well of these units compares favorably with that of band-wheel powers. The problems of peak load and proper counterbalancing have caused much study of strength and weight of materials. The use of dynamometers for the study of sucker-rod strains and stresses has led to improvement in material and design of rods, standing valves and working barrels in addition to putting pumping technique on a more scientific basis.

There is some tendency to geared powers as central pumping units. Powers are now available in which the gears, more carefully made than in older designs and of better material, run in a bath of oil.

Standardization

This review would not approach completeness without reference to the work of the Standardization Committee of the American Petroleum Institute, which, although in progress for several years, was largely completed in 1927. It is said that "specifications have been completed on

90 per cent. of the equipment used in the drilling and producing of oil." The extent of this activity may be realized if it is recalled that the sizes of joints and styles of rotary and cable tools, derricks and rig irons have been reduced from 626 to 33. In this entire program, which can only mean millions of dollars saved to the industry, engineers have played an important part.

Prospective Influence

The year 1928 finds the petroleum engineer in a vastly improved position for development and service. In the Petroleum Division of the A. I. M. E. he has a forum for free discussion of engineering problems and the development of new technique. In the American Petroleum Institute he has an avenue for converting accepted theory into common practice. In this organization the engineer speaks as an individual; in that, to a considerable extent as a representative of the industry. This is primarily a fact-finding group; that is a fact-using group. This is essentially a scientific organization; that, an executive organization. With these two avenues, one for the development of technique and one for effecting its adoption, petroleum engineering is in an enviable position and great should be its influence in the industry.

DISCUSSION

J. M. Lovejoy,* Tulsa, Okla.—The production engineer has advanced tremendously during 1927. In no other year has he really come so far to the front.

One of the chief results of the work of petroleum engineers during the past year has been to show the engineer himself, as well as the industry, that he must be backed up by more research and experimental work. He simply cannot solve many of the problems which he is now trying to solve with his seat of operations 4000 or 5000 ft. beyond his field of vision; he has to draw too much on his imagination and do altogether too much guesswork. I believe that if the industry through its various organizations will finance and support research and experimental work, the petroleum engineer will progress much more rapidly.

---

* Vice-president, Amerada Petroleum Corpn.

Chapter I. Air-gas Lift

Principles of the Air-gas Lift as Applied to Oil Production

By H. R. Pierce* and James O. Lewis,† Tulsa, Okla.

(Fort Worth Meeting, October, 1927)

Since the sudden revival of the air or gas-lift and its extensive use in the oil fields, many questions have arisen as to principles and as to their application under the conditions actually encountered in the field. Much has been written regarding both theory and practice, especially on the air-lift as applied to lifting water. Many statements have been made as to the use and benefits of the gas-lift, some of which are reasonable but many of which are unreasonable, many specialty makers claiming to have devices which operate in almost miraculous ways and even to generate energy nature never possessed. These claims are often based upon incomplete or inaccurate data.

A review of the literature discloses many valuable articles, but it also discloses the need for setting out more clearly the different practical ends sought, and for working out specific engineering principles upon which to formulate the design and operation of gas-lifts to meet the desired ends within the limitations of field conditions. A check on some of the published information has revealed basic errors in the sources of data upon which conclusions have been predicated and has led the writers to doubt the value of a large part of the compiled data.

The writers have concluded, therefore, that it will be opportune to direct discussion to the sources of error in the data now being collected, to recommend for consideration by the engineers some methods of collecting and correlating data, and to point out some of the factors relating to the application of the air-lift principle to oil production as dictated by the different economic ends sought, and the limitations of working conditions that may be met. Until these several considerations are clearly understood by the engineers, and the unreliable data have been sifted out and dependable data substituted, there seems little chance of evolving satisfactory engineering control for the air-lift.

In the following pages no distinction will be made between gas-lift and air-lift, as they are generically the same.

---

* Petroleum Engineer, Dunn & Lewis.

† Petroleum Engineer, Dunn & Lewis.

The Ends Sought

The ends sought in applying the air-lift will always be practical and not theoretical, though in arriving at a satisfactory solution of a practical end it is absolutely necessary to have correct guiding principles. Without endeavoring to make a complete outline of the ends sought, we will give the few main considerations and some of the practical limitations.

In many instances the primary consideration in applying the air-lift has been to increase the daily production to the greatest possible extent, regardless of all else. This is well illustrated at Seminole, where almost the only gage of efficiency, under the highly competitive conditions there, was the increase in daily production.

A second reason has been a desire for a cheaper method of lifting the oil—both as to installation and operating costs.

A third reason has been that in the very deep and crooked rotary holes which have been drilled in recent years, it was often impractical and sometimes even impossible to use the old deep-well plunger pump. This problem was the chief reason for the revival of the air-lift in California.

The fourth purpose has been the use of the air-lift as a means of increasing oil recovery as distinct from oil production. This results in a consideration of the effect of the back-pressure caused by the air-lift upon the expulsion of the oil from the sand as measured by the gas-oil ratio, though as pointed out in the following pages, the ratio of volumes of gas to oil alone is not a correct criterion of measuring recovery efficiency.

It is obvious that these four main ends will not always be reconcilable, and that the design and operation of a gas-lift will differ with the different standards of efficiency. Of course, there will not always be a clear distinction between the ends sought; often there will be a combination of two or more factors, but always the final end will be what the operator thinks the most profitable manner of operation under the existing circumstances. It will be the problem of the engineer to work out the best method and then to convince the operator that it is the most profitable manner of operation; but to accomplish this the engineer must be well fortified with the data which will enable him to design and operate his apparatus so as to fit the specific need most satisfactorily.

Practical Limitations

In working out these problems the engineer will be faced usually with very definite practical limitations. For example, tapered tubing will be limited to the size of the casing and it may not be possbile to use the most desirable graduations of flow pipe.

Other limitations will be the back-pressure, the occurrence of water with the oil and the emulsibility of the oil with the water, the kind of well equipment already on the ground, the relation of the air-lift to gasoline

extraction, the rock pressure and natural gas volume, whether or not the lift can be made continuous or intermittent, and so forth.

The main point is that theory must finally be adapted to the practical needs; the engineers need guiding principles and accurately gathered and analyzed data, which will enable the design of the proper installation with the least delay and the least necessity for experimentation.

The Theory of the Air-lift

The elements of the air-lift are shown in Fig. 1. One arm of the U-tube represents the submergence, the other the eduction, or flow tube. Water flows continuously into one arm where it reaches a level that counterbalances both the pressure at point of ejection in the flow tube and the pressure of the aerated column above the injection point, plus all other pressure losses in the eduction tube.

It can be seen at once that the three pressures must be theoretically equal at the point of ejection, the weight of the water in the flow tube plus the friction being equal to the pressure and weight of the air less the friction in the air pipe and also equal to the weight of the water and air plus the friction in the air pipe and also equal to the weight of the water and air plus the friction in the flow pipe, but as the forces are more kinetic in the flow pipe the effect is a flow in that direction.

In operation the water feeds continuously past the injection point and the air as continuously enters the upward-moving column and carries it up and out of the flow pipe. If the water is fed in more rapidly more air will be needed to remove it fast enough to maintain the same level in the submergence tube. Pressure failing, the submergence will be increased which will require a higher air pressure, and if the ingress of water is too rapid, it may overcome the air pressure and volume available and fill up both sides of the U-tube, thus stopping the flow. If the water flow is decreased, the submergence will be decreased, and the pressure at the injection point will be decreased likewise, but if the rate of water feed is dropped too low, the air will not lift the water and may pass alone up the flow pipe, and if the flow of the air is excessive the back-pressure caused by the friction and weight of the air in the pipe may exceed the pressure exerted by the water and cause some of the air to flow up the submergence end of the U-tube.

It will thus be seen that the air-lift consists of a balancing and proportioning of parts, pressures and volumes. For a continuous air-lift, the necessary elements are a pressure that will feed in the liquid to be lifted against the lift pressure and an equal pressure to feed in the air or other gas, the liquid pressure confining the gas pressure and directing its flow upward. The volume of the gas together with the pressure must contain the foot pounds of energy to lift the liquid against the frictional resistance,

and after the waste of energy caused by slippage or drop back of the water in the upflowing column. Thus the air pressures are controlled by the pressure resulting from weight and frictional resistance in the flow tube,

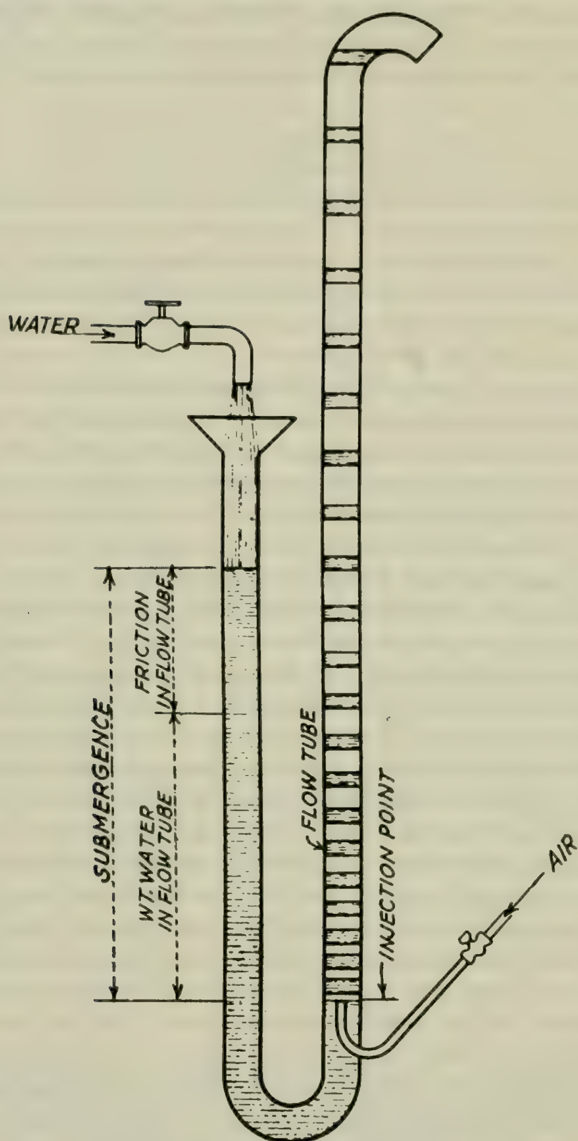


FIG. 1.—THE ELEMENTS OF THE AIR-LIFT.

and the volume of the air is controlled by the energy required at that pressure to overcome the weight and friction in the flow pipe plus the quantity of air wasted by reason of slippage.

In a naturally flowing oil well, the oil is fed into the bottom of the hole by means of the gas pressure and there is sufficient volume and pressure of gas to make a natural air-lift from the bottom of the well to the surface, but when the volume or pressure of the gas becomes insufficient, it is necessary to add additional quantities of gas or air from the surface.

Fig. 1 is diagrammatic and therefore the flow is shown as a series of separate slugs of water, whereas in fact a well-designed air-lift would show at the bottom of the well a mixture of finely divided bubbles of gas in the water and near the top, droplets of water in the air. Fig. 1 also shows with approximate accuracy the upward expansion of the air and the relative submergence which would be necessary to confine and balance the air injection and flow pressures. The summation of the thickness of the individual slugs will give the total length or weight of the column to which must be added the back-pressure resulting from friction.

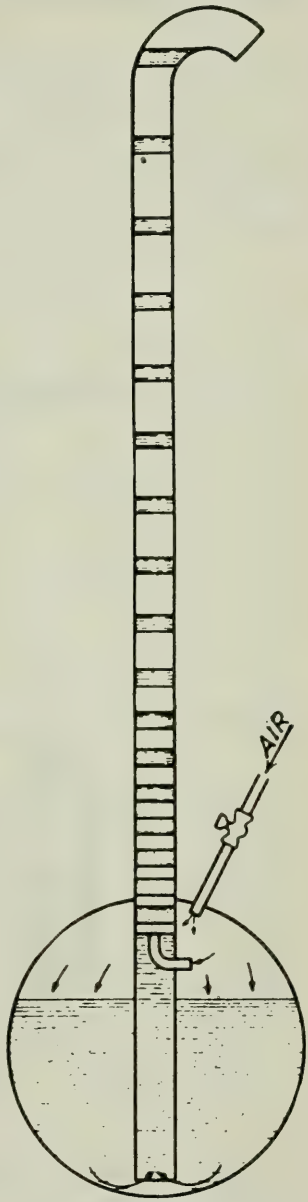


Fig. 2.—Principles of intermittent gas-lift.

Fig. 2 shows the principles of the intermittent gas-lift. The fluid accumulates in the bottom of the well in a chamber or in the hole of the well when the pressure is off the sand; air pressure is let into the well, which forces the fluid up into the eduction pipe, past an aperture in the pipe, through which a portion of the air enters and aerates the column above. The flow continues until all of the fluid is out of the well; then time must be given for a new charge of fluid to accumulate.

It is apparent (Fig. 1) that if the pressure is not maintained in the U-tube, or if the volume of air is too great, part of the air will flow up the short end of the U-tube, and will lift the water in that direction. This occurs in an oil well when the rock pressure becomes lower than the lifting pressure, the air or gas backing up into the sand and forcing the oil away from the well instead of lifting it out of the well. As a well becomes

older, this condition is met at some point and it becomes necessary to design and operate the air-lift with lower and lower pressures until

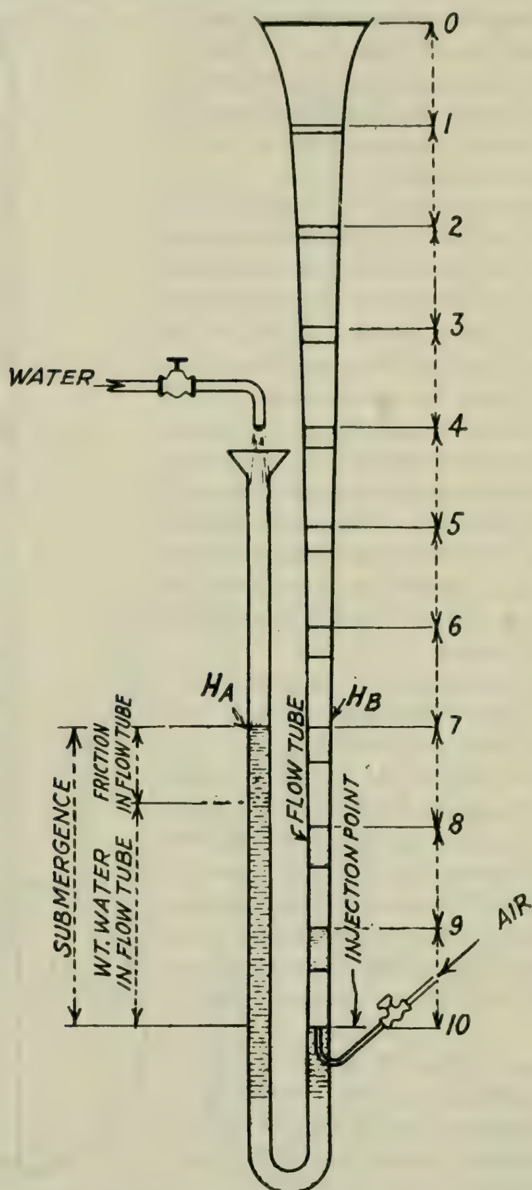


FIG. 3.—INCREASE IN CROSS-SECTION NECESSARY TO MAINTAIN CONSTANT VELOCITY IN UPFLOW OF WATER AND AIR.

finally it may be necessary to flow the well intermittently; if the sand is open, a chamber may be arranged in some practical manner while in

tight sands the well itself often will act satisfactorily as a chamber. Another, and more desirable plan, is to maintain rock pressure by injecting air or gas into the sand in near-by wells.

Fig. 1 shows how the gas expands upstream in the pipe. The relative spaces between the slugs of water show not only the expansion but the relative velocity of the flow of gas and water. To keep the velocity constant the cross-section of the pipe must be increased in proportion to the expansion of the gas. Fig. 3 shows with approximate accuracy the increase in the cross-section of pipe that would be necessary to maintain a constant velocity in the upflow of the water and the air.

Elements of Mechanical Efficiency

The three main elements consuming energy in the eduction of the liquid are (1) the weight of oil and the distance lifted, (2) the weight of the gas itself and distance lifted, (3) the frictional resistance of the upward-moving column of oil and gas, and (4) the slippage or dropback of the oil in the upward flowing gas. The first represents the useful work to be done, and, of course, is irreducible; therefore efforts to increase mechanical efficiency must primarily be directed to decreasing friction and slippage.

Friction increases with velocity according to well-known laws, but in the air-lift it is difficult to determine a friction constant for a well, and as there is an acceleration of velocity from the bottom to the top of the flow pipe the computation of total friction is an involved problem. This acceleration is graphically shown in Fig. 1, in which the relative velocity is indicated by the distance between the water slugs. The problem of friction is thus to keep down velocity.

Analyses of air-lift data by graphic and other means indicate that while friction increases with velocity, the slippage decreases with velocity; thus, where slippage predominates, friction tends to be the minor quantity, and vice versa, so that when we reduce one the other increases and our final problem is in keeping these two factors balanced so that their combined loss is a minimum. The fundamental laws governing the volume of a gas at different pressures, and the work available in gas due to its state, are very simple, but the methods of directing these laws, or rather, the arrangement of our equipment to obtain the greatest benefit, is our complicated problem. The various factors of this problem are:

1. Physical laws governing flow.

   a. The complicated laws governing the variation of friction of flowing gases and fluids. Although similar, the laws governing the friction of flowing water or oil, and gases, are not identical.

   b. The fact that the law governing the flow of either changes at some critical velocity.

   c. The fact that the relative quantities of gas and oil or water, or all three, are variable in any flowing column; that is, the relation of

quantity of gas and oil or gas, oil and water in the rising column varies from top to bottom of the eductor tube.

d. The change of the friction laws of the flowing constituents at some specific velocity.

e. The variation of volume and pressure of the gas, or pistoning, or lightening medium of the column.

2. The fact that slippage varies with nature of gas and fluid to be lifted, with the changes in the quantity relation of gas and fluid, and with the state of the gas.

3. The fact that oil wells are not drilled and cased especially for gas-lifts, and the rock pressure or submergences are not chosen for efficiency alone, but chiefly to allow the greatest quantity of oil to come into the well.

Producing oil by gas-lift is not merely a gas-lift problem; it is inseparable from and really a minor part of the oil-production problem, and as a consequence is complicated and involved, because of the limits imposed upon its operation.

The gas-lift in its simplest form has never been thoroughly analyzed or reduced to mathematical calculation, therefore we do not hope for a complete or definite mathematical analysis of all its adaptations to oil production whereby all conditions can be reduced to a common denominator, but we do believe that the combination of experience in various fields on which an intelligent, consistent analysis has been made will do much to eliminate the mistakes so common in the application of air-lift to oil production in new or untried wells or pools.

Although there is no doubt that oil can be produced in some instances more efficiently and more cheaply by the air-lift method than by other methods, in many cases a careful analysis at regular periods on the various wells on a lease would lead to more efficient work.

Collecting and Analyzing Evidence

The data necessary to determine whether a gas-lift would be beneficial in a pool on which the gas-lift has not been tried or experience factors set up are as follows:

A. General

1. Depth of sand.
2. Nature of sand or producing formation.
3. Whether well is flowing or has ever flowed, and for how long (see B).
4. Size of hole and how cased.
5. Whether oil was produced by gas or water drive, or the relation of the two, as nearly as possible, if both water and gas were used.

6. The initial production and relative rate of decline of oil, gas, and water.
7. Present rate of production as compared to other wells in pool similarly located and drilled.

B. Specific Information

1. If the well is flowing.
   a. Rock pressure of shut-in well.
   b. Nature of flow; that is, steady or by heads, etc.
   c. Quantity of oil, gas, and water produced by well against different back-pressures held on the head of the well. Three tests of this nature are desirable, the data to be worked up in the form given in Table 1.
2. If the well is not flowing, the quantity of oil and gas that the sand will deliver should be plotted against the head in feet of fluid above the top of the sand; that is, the oil level should be pumped, swabbed, or bailed down to three or more depths, and the quantity of oil and gas produced from these various places should be tabulated and plotted against pressure head of fluid above the sand. This pressure may be deduced from head and density of column, taking account of gas quantity in the column, gravities of gas, liquids, etc.

Table 1 illustrates the authors' method of working up for comparison the data gathered on flowing wells. From such tabulation, compared with experience factors and certain fundamental curves prepared to fit in with the experience factors and data, deductions can be made, indicating the present efficiency relation to a deduced possible efficiency of flow under improved methods and conditions. The advantages then may be balanced against the expense and time lost in making the needed changes.

Table 1.—*Method of Tabulating Data for Purposes of Comparison*

	Well 1	Well 2
1. Oil per day, bbl.	2,860	200
2. Water per day, bbl.		
3. Total fluid per day, bbl.	2,860	200
4. Total fluid per sec., cu. ft.	0.1861	0.0130
5. Gas furnished per day, M	480	650
6. Natural gas per day, M	1,305	185
7. Total gas per day, M	1,785	835
8. Total gas per sec., cu. ft.	20.68	9.67
9. Total gas-oil ratio, cu. ft. per bbl.	624	4,175
10. Furnished gas-oil ratio, cu. ft. per bbl.	168	3,250
11. Natural gas-oil ratio, cu. ft. per bbl.	456	925
12. Weight total liquid per sec., lb.	9.55	0.68
13. Weight total gas per sec., lb.	1.55	0.72
14. Total weight lifted per sec., lb.	11.10	1.40

TABLE 1.—*Method of Tabulating Data for Purposes of Comparison.—(Continued)*

	Well 1	Well 2
15. Depth of tubing, feet	4,216	4,108
16. Submergence, feet	1,340	264
17. Lift, feet	2,876	3,844
18. Velocity at top, ft./sec. 1/2	114.0	41.4
19. Velocity at bottom, ft./sec. 1/1	8.44	7.42
20. Difference in velocities ($V_2 - V_1$)	105.56	33.98
21. P_1 (abs.)	499.4	126.4
22. P_1 corrected (abs.) bottom well	493.0	109.7
23. P_2 corrected (abs.)	28.4	19.4
24. $R_1 \frac{P_1}{P_a}$	34.23	7.62
25. $R_2 \frac{P_1}{P_2}$	17.36	5.66
26. Total work in gas through R_1, ft.-lb./sec	151,500	40,700
27. Total work in gas through R_2, ft.-lb./sec	121,750	34,780
28. Total work lifting liquid + gas + acc., ft.-lb./sec	33,834	5,707
29. Total work lifting liquid, ft.-lb./sec	27,450	2,614
30. Total work lifting gas, ft.-lb./sec	4,460	2,768
31. Total work lifting acc. liquid + gas, ft.-lb./sec	1,924	25
32. Total work unaccounted for, ft.-lb./sec	87,916	29,373
33. $E_1 = \frac{\text{Work lifting liquid}}{\text{Work in gas through } R_2}$, per cent	22.60	7.53
34. $E_2 = \frac{\text{Work lifting gas}}{\text{Work in gas through } R_2}$, per cent	3.67	7.97
35. $E_3 = \frac{\text{Work of acceleration}}{\text{Work in gas through } R_2}$, per cent	1.58	.07
36. $E_4 = \frac{\text{Work lifting liquid + gas + acc.}}{\text{Work in gas through } R_2}$, per cent	27.85	15.57
37. $\frac{\text{Unaccounted for work}}{\text{Work in gas through } R_2}$, per cent	15.72	84.43

PRESSURE AND VOLUME OF AIR

Extensive experiments with the air-lift in raising water have shown that for each depth, size of pipe, and quantity of fluid to be lifted there are a certain pressure and volume which will give the greatest efficiency of lift. If the pressure is exceeded, less air volume will be used, but the total horsepower will be increased, and similarly, if a lesser pressure is used, more air is needed, and the total horsepower consumed is greater. The results of these experiments disclose a curve of the nature shown in Fig. 4, which is taken from a paper by Davis and Weidner,[1] the submergence corresponding to relative pressure.

An analogous curve can be made for the volume of air. There is a high point of efficiency with volumes and either more or less air will prove less efficient. If the volume becomes too great, not only will this relative efficiency be decreased but the actual quantity of the fluid lifted will be less because of the excessive energy consumed in lifting and overcoming the friction of the air itself.

[1] G. J. Davis and C. R. Weidner: An Investigation of the Air-lift Pump. *Bull.* 667, Univ. of Wisconsin (1914), 86. (See Fig. 24.)

For the maximum efficiency at each depth of well, the percentage of submergence or the relative pressure to the height of the lift is greatest in the shallow wells and becomes less and less with increasing depth of the well. The maximum efficiency obtainable likewise becomes very much less with deep wells. Thus, in Fig. 4, for wells of increasing depths there would be a series of similar curves of less output or efficiency, and with the point of maximum efficiency shifting to the left, thus showing decreased percentage of submergence or relative pressure.

In the oil fields the pressure and volume used will result not only from the considerations of the maximum efficiency obtainable but also

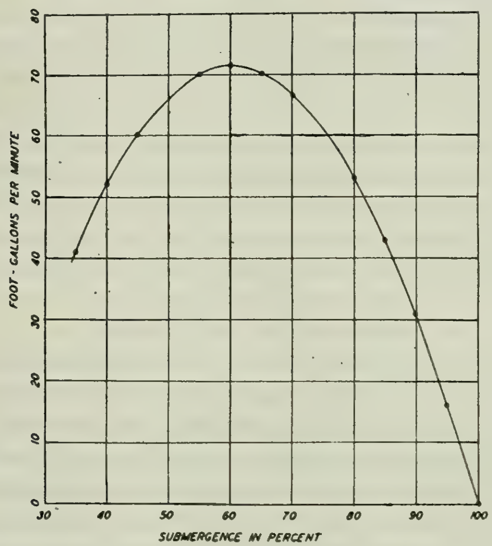


Fig. 4.—Relation of output to percentage of submergence.

from consideration of the ends desired and the practical limitations; for example, if it is desired to get the maximum daily production, efficiency would be given little weight and all efforts would be directed toward increasing the rapidity of flow to the point where the increasing friction placed a limit on the capacities of the eduction pipe. In another case it might be desired to hold a considerable back-pressure on the well which might exceed the pressure of maximum efficiency, and in still other cases the declining rock pressure will necessitate the use of flowing pressures much below the air pressure of maximum efficiency. In fact, in each well the use of the air-lift goes through a series of changes, often starting above the pressure of maximum efficiency and finally ending at a pressure so far below the most efficient that an air-lift becomes unusable as a continuous process.

Depth of the well obviously has a relation to both volume and pressure, inasmuch as more foot-pounds of work will be needed to lift the fluid the greater height, and also as friction and velocity will necessarily increase with the longer flow pipe. This results in the need for greater pressure and volume with depth and in a lower and lower percentage of efficiency as measured by the delivery of useful work.

Size of pipe also has an influence on the pressure and volume of air needed. A pipe of large cross-section relative to the amount of fluid to be lifted will reduce friction, but increase slippage and necessitate excess volume of air. On the other hand, too small a pipe will cause excessive friction and result in high pressures with low efficiency.

It may thus be seen that the pressures and volumes for maximum efficiency relate to the height of the lift and to the cross-section of the pipe relative to the volume being lifted. For each condition of depth and cross-section of pipe and relative quantity of fluid to be lifted, there is a certain relation of volume and pressure that will give the greatest efficiency but the engineer applying the air-lift in the oil fields should know not only how to estimate the point of greatest efficiency, but also how to best meet other conditions such as low rock pressure, or how to get the greatest daily production from a large well, if that is desired.

Use of Tapered Tubing

The use of tubing tapered downward is based upon the fact that as the gas approaches the top of the well the pressure becomes less; the gas expands and flows with increasing rapidity, thus greatly increasing the velocity. This is shown diagrammatically in Fig. 1, which represents a comparatively shallow well, the relative velocity being indicated by the space between the water slugs. In deep wells this velocity accelerates so much that the friction becomes enormous. At the bottom of the well the upward flow of the oil and gas is relatively slow, and probably much too slow for efficiency, considered from the standpoint of slippage. On the other hand, near the top of the well the flow is much too fast, considered from the standpoint of friction; therefore, the need is for a design which in effect will increase velocity at the bottom of a well and decrease velocity towards the top.

These considerations, long recognized, have led to the design of tapered tubing, which has been applied for many years in air-lifting water. The factors to be considered here are the practical design of tapered tubing under conditions met in the oil fields.

To design a tube so that there would be a constant velocity from top to bottom would mean that the cross-section of the tube should be increased upwardly in proportion to the expansion of the gas, as shown diagrammatically in Fig. 3, but this is obviously impossible in deep oil wells, and in fact would theoretically not be efficient because it would

cause extreme slippage. Therefore the design must be a compromise between slippage and friction, and the downward tapering of the tubing must be based on the intermediate factor, making the most efficient design one with an increasing velocity upward but not so great as in a straight pipe. The use of tapered tubing, especially in a deep well, is necessarily restricted to the size of the casing. To design a tubing in the correct proportions from the limit of size at the top would make it far too small at the bottom of the well. As a matter of fact, in a well of considerable capacity, tapering can be used only by sacrifice of daily production, and sometimes of actual efficiency, as a smaller size of tapered tubing would so restrict the cross-section of the pipe as to unduly limit the flow and create high frictional resistance that would result in a high back-pressure. Therefore it may not be practical to use any tapered tubing early in the life of the field when the conditions are competitive.

As the volume to be handled grows smaller, it will become possible to use tapered tubing effectively, which will result in a greater mechanical efficiency, if the tubing is properly designed, and also lower back-pressures at the bottom of the well.

In deciding on the taper, the engineer will have three problems: (1) the practical limitation of the largest size that can be used at the top of the well; (2) the smallest size that can be used at the bottom of the well to handle the volume of fluid without undue frictional resistance, curtailment of production, or back-pressure; and (3) the proper proportioning of the pipe between the maximum size at the top and the minimum size at the bottom. For efficient operation the graduations cannot be made at random, because there should be a mathematical relation between the lengths of the different sizes which will evolve the best compromise between the factors of slippage and velocity. There should be a gradual taper, not an abrupt change from one size to another, in order to minimize sudden changes in velocity.

If the use of tapered tubing proves of sufficient importance, it would be possible in many instances to case the well with a string of pipe having larger sizes near the top, in order to take advantage of this principle in deep wells, where the need for it is greatest.

Surface Flow Lines

As the velocity towards the top of the well increases, the factor of frictional resistance is of even greater moment at the surface of the ground than in the well itself. Shaw has called attention to surface equipment designed to reduce frictional resistance to a minimum, and incidentally to reduce the back-pressure at the top of the flow column in the well. This is applying correct and acceptable practices which have been used in the lifting of water, where the equipment for separation of air and water has received close attention. The value of reducing frictional resistance

at the top of the well by having large flow lines and separating the gas from the oil as close to the well as possible is exceedingly important, as can be shown by theoretical considerations backed by experience; for example, if the flowing pressure is 20 atm., and the pressure at top of the flow column in one case is 4 atm. and in the other case 2 atm., the expansion in the first instance is 5 times and in the second instance 10 times, with a resultant of 1.43 times the energy delivered. Of course, the useful work delivered is not increased 1.43 times, because of the increased friction caused by the increased velocity, but the over-all efficiency in almost every case will be increased considerably by keeping down the top pressures by proper design of surface flow equipment. The reduction in flow pressure at the bottom of the well is likewise reduced to an important extent.

Other Factors Relating to Efficiency

There are many other factors of the efficiency of the air-lift of which space will not permit more than mention. These include size of air and flow pipe, designs of footpieces, air injectors, the relative merits of annular and tubular flowing, the solubilities of air and gas and their relative advantages, the use of booster holes, intermittent air-lifts, and many others.

The air pipe can always be smaller than the flow pipe, yet there can be a surprising loss in pressure in small air pipes in deep wells which should be guarded against. To handle much fluid the flow pipe should be large, but if there is little fluid the slippage losses will be excessive, and in fact the air-lift may be inoperative. Where the fluid becomes small, tapered tubing should be used. Whether to use the central pipe as the air or flow pipe is mostly a practical matter as to the quantity of fluid to be flowed, the corrosion problems, and so on. Footpieces have been elaborately investigated and found to have but small influence on efficiency. The values of different designs of air injectors have also been exaggerated. Too few reliable and comparative data have come to the writers' attention as to the relative merits of gas and air to warrant the expression of any opinion. The intermittent air-lifts involve practical differences rather than theoretical differences.

Gas-oil Ratio

There has been much interest displayed as to the effect of the air-lift upon oil recovery. The evidence considered has consisted of curves showing the decline before and after the application of the lift and data showing the difference between the gas-oil ratios before and after use of the lift. Evidence and opinions have differed, and a general confusion is apparent as to both principles and results. The misunderstanding as to the use and significance of the gas-oil ratio is especially notable, therefore

it has been deemed advisable to set out what the writers believe to be the correct principles and use of this factor.

Some years ago the junior author[3] suggested the use of the volume of gas compared to the volume of oil as the measure of recovery efficiency, which since has been commonly termed the "gas-oil ratio" or "gas factor," but in applying this principle some of the fundamental elements have apparently been entirely overlooked, one of which is that the gas-oil ratio is a measure of relative efficiency only where other conditions are the same, and, secondly, that efficiency finally comes down to a matter of both pressure and volume of gas; that is, to the energy contained in the compressed gas which expels the oil. In the voluminous discussions of gas-oil ratios, we have seen no consideration of the fundamental principle, which is that the oil represents the useful work done by the energy contained by the gas, measured by volume and pressure in terms of horsepower or foot-pounds of work.

As a practical thing, the gas-oil ratio, as measured in volumes, can be used when limited to conditions otherwise comparable, which is in measuring efficiency of methods of operation on the same well at about the same time. Where, however, the gas-oil ratio is used to compare the efficiency of a process as applied to two different fields, two different properties, or even two different wells, it does not take into account the differences in the energy represented by a given volume of gas. Under such circumstances, therefore, it is essential that the pressure factor be taken into account and that the relative efficiencies be represented on a true comparative basis—that is, in foot-pounds of work—but in comparing the efficiencies in recovery between different wells, pools, or properties, it must be borne in mind that the efficiency of recovery is mostly determined by underground conditions, and that in measuring the efficiency of recovery at a well, one measures primarily the frictional resistance and slippage in the forcing of the oil through the sand to the well, and secondarily, the effect of the manner of operation of the well upon these recovery factors. Distinction should be kept between the energy used in overcoming natural conditions and the relative efficiency induced by manner of operation, the former being mostly uncontrollable by the operator.

There is also much confusion among engineers and operators as to the function of the gas-oil ratio. The opinion seems to be prevalent that the gas-oil ratio is a *cause* of efficiency, whereas it is only a *measure* of efficiency, just as the thermometer is a measure of a change in temperature but does not itself cause a change in temperature. The value of the gas-oil ratio is that it provides a simple and practicable means of measuring the sum of the results from the complex relation of many factors underground and in the well, which include the pressure, nature, and

[3] James O. Lewis: *Bull.* 148, U. S. Bur. of Mines (1916) 118.

volume of the gas, the distance the gas and oil have to travel to the hole, the resistance of movement of the oil through the sand by reason of friction, viscosity, adhesiveness to the sand grains, and other factors which consume or waste energy.

Inasmuch as the gas is a means for forcing the oil out of the sand, we are interested in so applying the means as to get a maximum quantity of useful work from it, this useful work being represented by the oil delivered to the tanks. In the sense as outlined here, the use of the gas-oil ratio, which more correctly could be termed the gas-pressure-oil ratio, is as fundamentally correct as a similar use in measuring the efficiency of the gas-lift alone or in a steam engine, gas engine, or any other mechanical contrivance deriving its energy from an expanding gas. We believe the question as to its utility as a measure of oil efficiency has come about through a misunderstanding of its fundamental principles and the resulting misapplication and confusion as to its utility. Until engineers clearly understand and correctly apply these principles the confusion will persist.

Determining Factor of Efficiency of Production

In order to point out the fallacy of basing oil-recovery efficiency on gas-oil ratios only, we will work out two specific problems, representing approximately the conditions existing in two pools, taking one well from each pool.

Well *A* is 4000 ft. deep and has 1200 lb. absolute rock pressure; it is flowing with 200 lb. absolute pressure at the sand face and 15 lb. absolute pressure at the well head. It is producing 3000 bbl. of oil per day with 1,500,000 cu. ft of gas of a gravity of 1.

Well *B* is 2000 ft. deep and has 325 lb. absolute rock pressure in the sand; it is flowing with 122 lb. absolute pressure at the sand face and 33 lb. absolute back-pressure at the well head. It is producing 600 bbl. of oil with 600,000 cu. ft. of gas per day of a gravity of 1.

In case *A* there is required 500 ft. of gas to produce 1 bbl. of oil from the sand, and in case *B*, there is required 1000 ft. of gas to produce 1 bbl. of oil from the sand.

Assuming isothermal work by the gas

	Case A	Case B
Number of foot-pounds required to expel oil from sand	5,560,000,000	1,110,000,000
Foot-pounds per barrel	1,855,000	1,855,000

(Values are approximate—worked out by 10-in. slide rule.)

That is, the actual energy used to expel 1 bbl. of oil from the sand is practically the same in *A* as it is in *B*, even though twice the number of cubic feet of gas per barrel of oil was used in *B*.

Still assuming isothemal work by the gas

	Case A	Case B
Foot-pounds (approximate) of work in gas in expanding from sand to surface	2,680,000	2,680,000

but this quantity of gas or energy was not sufficient to keep the wells flowing steadily under the above conditions, and it was in each case necessary to supply additional air, as follows:

	Case A	Case B
Additional gas supplied per day, cu. ft.	1,500,000	600,000
Total gas used per day, cu. ft.	3,000,000	1,200,000

Therefore:

	Case A	Case B
Foot-pounds (approximate) of work used in lifting oil	16,000,000,000	3,200,000,000
Foot-pounds (approximate) per bbl.	5,360,000	5,360,000

Hence:

	Case A	Case B
Efficiency of lifting oil only, gas assuming isothermal expansion, with oil of 86 sp. gr.	22.3 per cent.	11.15 per cent.

Estimating Compressor Capacity and Horsepower of Driving Unit

The following problem is given to show the size of compressor and engine required to furnish the additional gas necessary to flow the two representative wells in the previous example.

Assuming adiabatic compression, and allowing for loss in friction and slippage in the compressor transmission and mechanical efficiency of the machine

	Case A	Case B
Horsepower of gas engine to pull compressor to deliver necessary air	335	112

Assuming 14 per cent. thermal efficiency and a gas of 1200 B.t.u. per cu. ft.

	Case A	Case B
Cu. ft. per day required as fuel for gas engine	129,000	41,000

Energy in Terms of Horsepower

If it were necessary to furnish all the energy used by these two wells in the expulsion of the oil from the sand and raising it to the surface, we would have to install units as follows:

	Case A	Case B
Unit required, hp.	1214	287
Per barrel of oil, hp.	0.405	0.478

Table 2 gives a complete analysis of the energy distribution of these two wells.

TABLE 2.—*Complete Analysis of Energy Distribution from Wells A and B*

	A	*B*	Per Bbl. of Oil		Total Horsepower		Horsepower per Bbl. of Oil	
			A	*B*	*A*	*B*	*A*	*B*
Well depth, ft. from surface	4,000	2,000						
Back-pressure or pressure in the sand, lb. per sq. in. abs	1,200	325						
Back-pressure against face of sand or pressure at bottom of well, lb. per sq. in. abs	200	122						
Discharge pressure or pressure at well mouth, lb. per sq. in. abs	15	33						
PRODUCTION								
Oil daily, sp. gr. .86, bbl	3,000	600						
Gas with oil from the sand, M cu. ft	1,500	600						
Additional gas added at bottom to cause well to flow, M cu. ft	1,500	600						
Total gas necessary to flow oil from bottom of well to surface, M cu. ft	3,000	1,200						
ENERGY ISOTHERMAL EXPANSION								
To expel oil from sand, millions ft.-lb	5,573	1,160	1.857	1.934	117.3	24.4	0.0390	0.0406
To raise oil from bottom of well to surface, million ft.-lb	16,100	3,257	5.370	5.425	338.5	68.4	0.1130	0.1140
Total energy required to expel oil from sand and lift it to surface, million ft.-lb	21,673	4,417	7.227	7.359	455.8	92.8	0.1520	0.1546
WORK ACTUALLY ACCOUNTED FOR								
Moving oil through sand to well bore, million ft.-lb	?	?	?	?	?	?	?	?
Lifting oil to surface from bottom of well million ft.-lb	3,610	361	1.203	602	76.0	7.6	0.0253	0.1275
EFFICIENCY OF								
Expulsion of oil from sand, per cent	?	?	?	?	?	?	?	?
Efficiency of lifting or flowing oil from bottom of well to surface, per cent	22.41	11.08	22.41	11.08	22.41	11.08	22.41	11.08
ADIABATIC FT. LB. OF WORK BY ADIABATIC COMPRESSION SHOULD ALL THE ENERGY BE FURNISHED BY A COMPRESSOR TO								
Expel oil from sand	6,360	1,314	2.120	2.190	133.7	27.6	0.0444	0.046
Lift oil to surface, assuming 14.4 lb. intake	19,900	5,190	6.640	8.650	419.0	109.0	0.1395	0.182
Furnish total energy for expulsion and lifting	26,260	6,504	8.760	10.840	552.7	136.6	0.1839	0.228
ADDITIONAL WORK ADDED BY ADIABATIC COMPRESSION IN FURNISHING								
Additional gas necessary to cause well to flow	9,950	2,595	3.320	4.325	209.5	54.6	0.070	0.091

Horsepower = 33,000 ft.-lb. per min.

All values were worked out on a slide rule and are approximate, but are accurate enough for all practical purposes.

Gas quantities are all reduced to quantity at 14.4 lb. and 60° F. All energy units are based on these conditions also.

RELATION OF AIR-LIFT TO OIL-RECOVERY EFFICIENCY

It has been necessary to divert from the subject in hand in order to prepare the ground for a discussion of the relation of the air-lift to efficiency in oil recovery. There have been some statements of mysterious effects of the air-lift on recovery as measured by gas-oil ratios and there

have also been statements that the air-lift has been detrimental as measured by the same criteria.

So far as the writers can see, the air-lift has two effects on the efficiency of oil recovery: one, by reason of changes of back-pressure against the sand, and the other by reason of its effect upon the condition at the bottom of the hole. The last factor is comparatively of less importance, and therefore will be covered by stating that the gas-lift tends to remove the sand, mud, and other matter from the hole, thus keeping the hole clean. However, it can also be so applied as to paraffin up a sand and thus harm the well.

It seems doubtful whether the gas-lift has any important effect on recovery other than the back-pressure applied against the face of the sand; therefore, the discussion of the effect of the air-lift on efficiency of oil recovery comes back to the same controversial question as to the manner of operation and utility of the back-pressures. Without presenting evidence or analytical reasons for their opinion, the writers wish to say that they believe that the back-pressure will be beneficial or not wholly in accordance with the degree of pressure applied, and the manner of applying it in relation to the local conditions. When the junior author discussed this subject in *Bulletin* No. 148, of the Bureau of Mines, he called attention to the fact that too high a back-pressure would be detrimental, but, on the other hand, there was much evidence that at some point there would be a back-pressure for each condition which would be beneficial just as there has been shown to be an optimum submergence or confining pressure for the air-lift with relation to the other concurrent conditions.

A high back-pressure prohibits the full expansion of gas and thus lessens the amount of energy delivered by it. On the other hand, if the gas is allowed to expand to its maximum extent, the additional work delivered will be largely consumed in greater velocity and, therefore, greater friction, so that the additional useful work theoretically available will be small. Furthermore, there is good reason to believe that the higher velocities created will result in greater slippage of the gas through the sand. Also, Henry L. Doherty has demonstrated that taking the gas out of solution from the oil will have an important and seemingly detrimental effect on the physical properties of the oil.

These lines of evidence are reasoned out by a careful consideration of the results from applying back-pressure both under artificial pressure and under natural pressure. The seemingly irreconcilable results reported by various observers of back-pressure both when used with air-lifts and elsewhere can be explained by the fact that account must be taken of the limited range in which back-pressure can be advantageously used, which, if either less or more, will be harmful.

With respect to the term "back-pressure" there has been a similar confusion of thought as with the term "gas-oil ratio." The virtue of the pressure held against a well is in the change in differential pressure created between the pressures in the sand and in the well. It is this differential pressure that causes the movement of the oil and gas, and that is important. We would have clearer thoughts on the subject if we thought in terms of differential pressure rather than in terms of back-pressure.

That the high differential pressures between the oil sand and the pressure at the bottom of the hole are largely used up otherwise than in recovery efficiency may be inferred from observational data on the relation of the gas-oil ratio to declining production. At first thought it would seem that, because there was less energy in each thousand feet of gas when the pressure declined, the volume of gas necessary to move each barrel of oil would be increased greatly. A further reason for thinking that this supposition would be true is that in a more depleted sand a greater proportion of the energy is wasted by slippage, but as a matter of fact we find that taken as a whole the gas-oil ratio does not increase greatly as the pressure goes off, and in some instances the volume of gas with each barrel of oil decreases over a considerable period of time. It would appear from this evidence that the increased energy released by holding a low back-pressure and thus a high differential pressure is used up mostly in forms of work that do not increase recovery. Experience in repressuring sands leads to similar conclusions. There is probably a curve of efficiency in recovery for each well with respect to the differential pressure that is analogous to the relation between pressure and efficiency in the air-lift as shown by Fig. 4.

If the writers are correct in their conclusions, the effect of the air-lift upon oil recovery is to be measured by the back-pressure created by it and the air-lift should be designed and operated at a pressure to conform with the back-pressure giving the best results in oil recovery.

These considerations, however, are limited by the practical ones of the competitive conditions at the well and therefore the necessity for getting the highest daily production. Not until a great deal more observational data have been collected and analyzed can it be known how to work out the use of back-pressures and how to design the air-lift so as to get the back-pressures desired, and at the same time have an efficient air-lift within the limits imposed by the size of the casing and other economic and practical conditions.

It may at first thought seem that the air-lift, which, in a deep well, may be imposing several hundred pounds of pressure at the bottom of the well, would create a back-pressure instead of lessening the back-pressure, but, actually, a naturally flowing well may have a greater back-pressure on the sand than is necessary to lift the oil by the air-lift,

and this is true even with a pumping well. If the oil flowing into the well is not removed as fast as it enters, it heads up and exerts a strong back-pressure, as has been shown in discussing Fig. 1. This will take place if the pump has not sufficient capacity, or in a flowing well if the pressure and volume of the gas does not supply enough energy to lift the oil rapidly. Under these conditions the air-lift, by removing the accumulated column of oil, will actually reduce the pressure on the sand.

Need for Better Information

Tests made on the deliveries of air compressors have disclosed that assumptions as to their delivery, horsepower, and efficiency founded upon manufacturer's claims and ratings are very unreliable, and conclusions based upon such data should not be accepted. As operated in the field, a compressor has not the same efficiency as when tested on the floor of the factory. Analogous errors have been noted in other observational data. Progress in air-lift engineering will not be satisfactory until the information gathered in the field is more complete and dependable.

DISCUSSION

R. R. Brandenthaler,* Bartlesville, Okla.—This paper is one of the best that have been written on the principles of the air-gas lift. Certainly it emphasizes the need for fundamental experimental work and accurate, pertinent data as a basis for future development.

I was much interested in the comments regarding the necessity for setting out more clearly the different practical ends sought and for working out specific engineering principles upon which to formulate the design and operation of gas-lifts to meet the desired end. Unless this is accomplished, there is not likely to be any material advancement in the development of the gas-lift.

The differences in opinion relating to the gas-lift are sufficient justification of the statement that there are basic errors in the source of data upon which conclusions have been predicated. Unfortunately, economic necessity has centered interest primarily on obtaining the maximum daily oil production, little recognition being given the possible effect on ultimate production. Some records have been more complete than others, but there is still much to be desired as regards complete and accurate records.

Lewis and Pierce bring out an important consideration; that is, the question of velocity in the oil line. This was demonstrated by the small gas-lift model exhibited by the U. S. Bureau of Mines at the Tulsa Exposition. Varying the velocity had a decided effect on the type of flow obtainable.

The Bartlesville Station of the U. S. Bureau of Mines is planning a series of experiments with natural flow and the gas-lift. A derrick has been erected, of which the crow's-nest will represent the surface of the ground; a large tank placed under the derrick floor will represent an oil structure. While we all recognize the possible limitations in the height of lift, the total lift being 85 ft., we believe that pertinent fundamental data may be obtained in the contemplated experiments by working with smaller sizes of tubing and casing. For each experiment it will be possible to recharge

---

* Petroleum Engineer, U. S. Bureau of Mines.

the reservoir tank with the same volume of oil and gas, hence quantitative comparisons can be made between experiments.

The various companies in the Mid-Continent will be notified prior to each experiment, so that they may send representatives to witness the experiments. Suggestions concerning the contemplated experimental work will be much appreciated.

W. E. Wrather,* Dallas, Tex.—Has tapered tubing been used in the Seminole field?

J. M. Lovejoy,† Tulsa, Okla.—I think it has been used in the experiments.

Member.—Have lift operations been tried through 4-in. tubing tapered down to a string of 2 inch?

E. V. Foran,‡ Breckenridge, Tex.—The Marland Oil Co. has made some experiments under the conditions just mentioned, in a well that has made from 300 to 1000 bbl. a day from 2500 ft. in depth. The results of that will be given a little later in the session.

C. V. Millikan,§ Tulsa, Okla.—In further answer to Mr. Wrather's question: The Amerada Petroleum Corpn. has conducted some experiments along that line. On wells 1300 ft. deep making from 50 to 100 bbl. flowing through 2-in. regular tubing, the working pressure was reduced from 100 lb. to 50 lb. by using a tubing graduated 2, 2½ and 3 in. At one well in Seminole making 150 bbl. of fluid through 2½-in. tubing, the working pressure was reduced about 20 lb. by using a graduated string of 2, 2½ and 3 in. There was no change in volume of fluid handled at either place.

Member.—The man in attendance at the exhibit at Tulsa, in talking of tapered tubing, said that in a well 4200 ft. deep ideal conditions would call for 2½-in. tubing at the bottom with a gradual increase to 42 ft. in diameter at the top. I told him I did not think there would be any production with such conditions.

E. H. Griswold,|| Ponca City, Okla.—We have found that with both natural and gas-lift flowing wells, there exists a critical back-pressure for each well. Pressure above and below this critical pressure tends to increase the gas factors. The critical pressure varies with the life of the well and frequent adjustments are necessary. It is thought that the use of back-pressure has often been condemned because pressures in excess of the critical point were applied. Some wells are pinched beyond their critical pressure by the accidental or unavoidable use of too small a flow pipe and of course are not subject to the use of increased pressures.

It is rarely economical to change the size of flow pipe more than once or twice in the gas-lift life of a well. Controlled back-pressures have been used to maintain efficient flow during the periods between changes of tubing sizes.

Velocities as low as 15 ft. per second and as high as 100 ft. per second have been found at the well head on different wells at their most efficient points. Just what the most efficient velocities are for various combinations of gas and oil production, size of flow pipe, etc., have not been determined; but it is believed that with the data now being assembled some general correlation at least can be made.

---

* Consulting Geologist.

† Vice-president, Amerada Petroleum Corpn.

‡ Production Engineer, Marland Oil Co. of Texas.

§ Petroleum Engineer, Amerada Petroleum Corpn.

|| Petroleum Engineering Dept., Marland Oil Co. of Oklahoma.

Effect of the Gas-lift on the Physical Properties of Oil*

By R. R. Brandenthaler, Bartlesville, Okla.

(Fort Worth Meeting, October, 1927)

Petroleum producers in the Mid-Continent field, up to the present time, have been more concerned with the mechanical operation and efficiency of the gas-lift than with its possible effects on the physical properties of the oil. As a result few specific data are available on the subject and contradictory opinions exist. Some operators are positive that the gravity of the oil is decreased, while others present data which definitely show that the gravity of the oil is increased. In other localities, some operators have given careful attention to the effect of the gas-lift on the gravity of the oil. When the emulsions formed have given much trouble, the problem has usually been dodged by placing the well on the pump.

Certain Fundamentals

Certain fundamental results may be expected under ordinary conditions and with all types of crude oil, when gas is the prime mover of oil in producing formations. For example, the gravity of oil will decrease as the rock pressure in the producing formation declines, the change being greater in the higher gravity oils.

Furthermore, the character of emulsion formed is primarily dependent on the kind of oil, thus more refractory emulsions are formed from asphaltic-base oils, less refractory from mixed-base oils, and the least refractory from paraffin-base oils. However, refractory emulsions are sometimes formed from paraffin or mixed-base oils that are difficult to treat by ordinary methods, especially by electrolytic processes. With oils having the same base, those of lighter gravity are less subject to the formation of emulsions, especially of refractory emulsions.

There are two types of emulsions formed; namely, water-in-oil emulsions and oil-in-water emulsions. The former are the more common; in fact, very few examples of oil-in-water emulsions have been noted in the oil fields. The amount of water produced with the oil influences the percentage of emulsion formed. Agitation and velocity of flow play an important part in the forming of emulsions.

---

* Presented by permission of the Director, U. S. Bureau of Mines. Petroleum Engineer, U. S. Bureau of Mines.

Effect of Other Producing Methods on Physical Properties of Crude Oils

For comparison, the effects of other producing methods on the physical properties of crude oil are briefly summarized. In a natural flowing well in which water is present, surging will cause emulsions to form and the degree of emulsification is influenced by the extent of surging. By installing the correct size and length of tubing and applying pressure control, surging can be stopped temporarily. It may recur when the rock pressure declines, in which event tubing of smaller diameter replacing the former string may again eliminate it. In either case, by steadying the flow the velocity is increased sufficiently to prevent the dropping back of fluid, thus lessening the agitation which in turn lessens the percentage of emulsion formed. Swabbing, which causes agitation, may result in the forming of emulsions when the swab is run too low in the fluid and water is present. When a swab is used to skim the oil, emulsions are not formed so readily. Emulsions are also formed in pumping but to a lesser degree than with other methods, when pumping is carried on efficiently.

Changes in gravity of oil may be affected by the manner of application of the different producing methods. As the rock pressure declines the gravity of the oil decreases, but by controlling the well and trap pressures, the decline in gravity may be retarded or may be temporarily increased. After the pumping stage has been reached, the gravity of the oil will remain fairly constant unless vacuum is applied, in which event the gravity is generally decreased and the decrease is proportional to the amount of vacuum held.

In general, the producing of oil under pressure results in an increase in gravity. This increase may be relatively small or often only sufficient to retard the natural decrease in gravity resulting from declining rock pressure and withdrawal of oil from the formation.

Effect of the Gas-lift on Physical Properties of Oil

The effects of the gas-lift on the physical properties of oil have been classified under the following headings:

1. Formation of emulsions.
2. Change in the gravity of oil.
3. Changes due to heat.
4. Changes due to oxidation when air is used.

As more data on these phases of the use of the gas-lift become available, additional methods will be devised for overcoming the difficulties. Fortunately, in the Seminole area, where most of the gas-lift work in the Mid-Continent has been carried on, emulsion problems have not been very serious. This is primarily on account of the kind of oil

produced. Emulsions formed have been readily broken down without serious difficulty.

Formation of Emulsions

A general survey of fields throughout the country indicates that the use of the gas-lift, irrespective of the type of oil, results in an increase in the percentage of emulsions formed and also in more refractory emulsions. This condition is more pronounced in localities where asphaltic-base oil is produced. One engineer reports that in a number of wells operated by his company, the gas-lift was removed because of the refractory emulsions formed. Greater agitation in the fluid column caused by the introduction of gas or air accounts for the increase in percentage and refractory properties of the emulsion. Possible exceptions to the general rule are instances where the velocity and pressures are controlled in a manner similar to that used by some companies in applying pressure control. That is either by installing the tubing at some distance above the sand and flowing through the tubing or by flowing through the tubing and holding pressure either at the well head or trap.

As the percentage of water produced increases beyond approximately 15 to 20 per cent., the percentage of emulsion decreases. This condition holds generally with all types of oil and may be accounted for by the fact that the presence of a large quantity of water lessens the possibilities of films of water being formed and remaining around globules of oil.

In the Seminole area a natural flowing well produced 5500 bbl. of oil and 6 per cent. of water. The 7 per cent. emulsion formed was easily treated out with a small amount of tret-o-lite. The gas-lift was then installed and on the day of installation a 37 per cent. water-in-oil emulsion was formed, which was more difficult to treat. More tret-o-lite and heat were required to break down the emulsion. On another well in the same area, a 4 per cent. emulsion was produced prior to installing the gas-lift. After the gas-lift was installed, the emulsion increased to 64 per cent. Another well registered an increase in emulsion from 7 per cent. prior to installing the gas-lift to 82 per cent. after installation. All of these wells produced from between the tubing and casing. In every instance where a large percentage of emulsion was formed the water produced did not exceed 15 to 20 per cent. of the well's total daily production.

In the Tonkawa and Garber fields, and especially in the latter field, large quantities of water are produced with the oil, and a relatively small percentage of emulsion is formed.

D. B. Dow[1] says, "The use of the gas-lift may be advantageous in some fields but at most wells persistent emulsions have been formed when the oil and water are agitated violently by the compressed air as

---

[1] D. B. Dow: Oil Field Emulsions. U. S. Bur. of Mines *Bull.* 250 (1926).

they rise in the well. The persistence of emulsions formed in this way depends upon the character of the oil. In the Gulf Coast field, where the air is used extensively, permanent emulsions that require special treatment are formed. In the West Columbia field, Texas, cut oil produced in certain wells in the east pool breaks down quite rapidly, whereas in the north field the emulsion is most persistent. However, the oil from the east pool is lighter in gravity and is produced at a little higher temperature than that from the north field."

Effect of Air and Gas on Gravity of Oil

Logically, one would be safe in assuming that the introduction of air or gas would result in a decrease in the gravity of the oil being produced. The treated gas contains only such gasoline as has not been removed in the gasoline-extraction plant, ordinarily not more than from one-tenth to one-twentieth of a gallon per thousand cubic feet of gas. When again recovered after being introduced in a well, the gasoline content has increased to one gallon or more per thousand cubic feet. As the oil must furnish the additional gasoline, it is reasonable to conclude that the gravity of the oil has been decreased. Tests made in the Mid-Continent have shown that the gravity of the oil has been actually increased when gas is used. With air the increase was only nominal, that is increases of only one-tenth or two-tenths of a degree were noted. Higher pressures and velocities probably account for the increase in gravity. Further investigation to determine whether the increase is temporary would be interesting. The weathering of two samples, one obtained from a natural flowing well and another from a well on the gas-lift may result in a change in our ideas. It has even been suggested that the decrease in gravity of the latter sample would be greater because of the removal of certain fractions by the scrubbing action of the dissolved gas.

A survey of the effect of air or gas on the gravity of the oil indicates that the effect differs to some extent with different types of oil; that is, asphalt base, mixed base or paraffin base, the first being affected least and the latter being affected most. However, the gravity of the oil is more of a factor than the type of oil, oils with a higher gravity being subject to greater change.

Changes in the volume of gas used also affect the gravity of the oil, larger volumes usually resulting in a gravity decrease.

A series of tests carried on in the Seminole area gave the following results: Over a period of five days of natural flow, the gravity of the oil averaged 39.4° A. P. I. The average gravity over a period of 20 days on the gas-lift amounted to 40.7° A. P. I. When the gas was replaced by air, the average gravity during a period of five days was 39.5° A. P. I.

Thus, when air was used there was an apparent increase of 0.1° A. P. I. in the gravity of the oil and an increase of 1.3° A. P. I. with gas over natural flow.

Another test conducted on seven wells over a period of 10 days resulted in no apparent increase with air and an average increase of 1.04° A. P. I. when gas was introduced. The oil samples were obtained at the trap. This increase in gravity was also noted in the pipe-line runs. Some companies report a decrease in gravity of oil in the Seminole area, but I have no definite information to substantiate this statement.

A series of tests on eight wells were made on another type of oil in another section of the country. The average gravity during natural flow was 28.7° A. P. I. and when on the gas-lift it was 28.6° A. P. I., a difference of only one-tenth degree.

Four other wells in the same locality were tested, with the following results:

Average gravity during natural flow	25.8° A. P. I.
Average gravity during gas-lift flow	24.8° A. P. I.
Average per cent. cut oil during natural flow	0.8
Average per cent. cut oil during gas-lift flow	0.73
Per cent. gasoline content of crude oil during natural flow	21.3
Per cent. gasoline content of crude oil during gas-lift flow	18.3

The gravity of the oil had been decreased one degree. Average per cent. of cut oil during natural flow and while on the gas-lift was approximately the same. A decrease of 3 per cent. in the gasoline content of the crude occurred while the gas-lift was used.

Changes Due to Heat

The utilization of heated gas or air in flowing wells has been used primarily for decreasing the viscosity of low-gravity oils and in a number of instances the increase in production has been very noticeable. As practically all gas-lift work is confined to high-gravity oils in the Mid-Continent few data are available on the subject. From a general observation of field operations in this area and discussion with other engineers, I have concluded that the use of preheated gas has not resulted in a permanent increase in gravity of oil produced or in an increase in oil production in the Seminole area.

Increasing the temperature of an oil renders it less viscous but at the same time allows for less gas to be dissolved in it at higher temperatures. Thus, with an oil of the character produced in the Seminole area, the gravity of crude would be less at higher temperatures.

Changes Due to Oxidation

It is possible that the use of air has resulted in some oxidation of the crude oil, an example of which was called to my attention. One well, while flowing naturally produced oil of a greenish color having a gravity of 39.6° A. P. I. No water was present. Ten days after the air-lift was installed the gravity of the oil had decreased more than one degree A. P. I. and the oil had changed to a slightly yellow color. Information on the subject of oxidation of crude oil when air is used is contradictory. Without more conclusive proof, I would hesitate to state that oxidation actually takes place. It is hoped that further investigation will be carried on to furnish conclusive data on the problem.

Conclusions

In dealing with the effect of the gas-lift or air-lift on the physical properties of oil, the method of application is important. Agitation of the fluid column can be minimized by making the proper type of installation, and with correct operation.

Flowing between tubing and casing results in greater agitation on account of the tubing collars and further disturbance in flow at the well head between the tubing and casing. The use of tubing with larger diameter rather than flow between the tubing and casing is recommended, if necessary to accommodate production. A control of flow velocity will also aid to minimize emulsion difficulties. Either too low or too high a velocity tends to increase the percentage of emulsion. Holding pressure at the trap will often accomplish good results, but one objection to this is the eventual loss of the higher or more volatile hydrocarbons: these are held in solution in the oil and are later lost beyond recovery. While the ordinary types of flow nipples used at the well head tend to increase the percentage of emulsion, the new adjustable type has apparently eliminated some of this difficulty.

DISCUSSION

J. B. Umpleby,* Oklahoma City, Okla.—Mr. Brandenthaler's paper is particularly timely. I would like to add that in oils where reduction in gravity occurs it is accompanied by a very serious reduction in volume. In the Bradford field, in experimenting with the air-lift, we found that the gravity fell about 4° and that the volume fell about 12.5 per cent.

Member.—In the Bradford field, was pressure applied constantly or intermittently?

J. B. Umpleby.—We are trying to restore rock pressure on two properties at Bradford and in this work pressure is applied constantly. In air-lift experiments, however,

---

* President, Goldelline Oil Corpn.

the very small size of wells makes intermittent operation necessary. In wells 2000 ft. deep we have found that three or four booster collars spaced at 200-ft. intervals up the tubing reduce the necessary starting pressure to about 200 lb. This is an application of the principle illustrated in Fig. 2 of Pierce and Lewis' paper. Flow is upward through the tubing and the flowing period is 30 min. or less each day. Pressure is entirely removed from the face of the sand between flows.

M. Walker,* Tulsa, Okla.—We have run some experiments that indicate that a crude oil having an initial gravity of 35° Bé. had a gravity of 33.4, 34.2, and 34.7° Bé. when produced by a gas-lift installation in which the submergence was held at 19, 34, and 50 per cent. respectively. Or a decrease in submergence from 50 to 19 per cent. caused a decrease in gravity from 34.7 to 33.4° Bé., using a crude oil of which the gravity was 35° Bé. before pumping.

R. Van A. Mills,† Bartlesville, Okla.—It has been suggested that thickening of oil during air-lift operations is due partly to the oxidation of the oil. This matter of oxidation is of considerable importance to our investigations in the Bureau of Mines at the present time, especially in connection with repressuring oil sands with air.

We have had a number of trouble calls—people having difficulty on account of the thickened character of the oil after they started repressuring with air have called upon us to help them out of the trouble, which they attribute to oxidation of the oil. We have investigated a number of these cases and have found that the bad oil which the pipe line would not take was in reality a water-in-oil emulsion. We have found no actual proof that oxidation of the oil has occurred although we have found 10, 15, 20, even 30 per cent. of CO_2 in the casinghead gas on properties being repressured with air. In some places the oxygen of the air appears to have disappeared entirely whereas in others considerable oxygen remains in the gas. We have analyzed gas-air mixtures on repressured properties where the gas has become inert and useless for fuel or power purposes and have found as much as 77 per cent. nitrogen, 7 per cent. CO_2 and 6 per cent. free oxygen. There is nothing consistent about these analyses except that nearly all of them indicate the consumption of oxygen to form CO_2. This is certainly indicative of oxidation, but it does not prove that the oil itself is being oxidized. If anyone has proof that there is oxidation of oil, we shall be glad to have him present it.

E. O. Bennett.—Some time ago, when I was in the Bureau of Mines, we made an analysis of oil that had air on it for five years and the sample checked with the samples taken before the air was put on. That was only in one field. We have recently found that air tends to produce cut oil and prefer to use gas wherever it is available.

C. B. Williams,‡ Cisco, Texas.—The Texas Co. has a lease in Callahan County, Texas, which has been repressured with a mixture of air and gas for a period of one year. The casinghead gas has been continuously recycled during that time and the CO_2 content has increased from 0.2 to 5 per cent. That this increase has been gradual has been shown by periodical analyses of the returned gas made with the Orsat apparatus.

J. B. Umpleby.—With the great solubility of CO_2 in oil and its effect in reducing viscosity there is a compensating relationship between the increase in CO_2 and possible oxidation of the oil. If anyone has determined the source of the CO_2 in air-pressuring operations I would like to hear them discuss the subject. It is perhaps

* Amerada Petroleum Co.

† U. S. Bureau of Mines.

‡ The Texas Co.

reasonable to consider it a product of oxidation of the oil and yet so far as I have been able to determine the oil itself does not show oxidation. In a few fields the oil becomes heavier as a result of repressuring but in most cases it becomes lighter. Even in the exceptional fields the result may well be due to topping instead of oxidation.

W. Van Der Gracht,* Ponca City, Okla.—The CO_2 that is produced when air is introduced into an oil sand indicates that there is oxidation; but what is oxidized and where are the other oxidation products of these reactions? Is it not possible that, with the exception of CO_2, they all remain behind in the sand, leaving the oil itself exactly as it was before air was introduced—that it is not the oil that is oxidized, but other things?

As a rule, oil deposits are rich in sulfur; sulfides as well as free H_2S. If oxygen is introduced, in the presence of moisture, acids are formed which react with the nearly always present carbonates, yielding sulfates and CO_2. When CH_4 is present, the sulfates can again be reduced, again yielding CO_2 in this reaction. Höfer gives the following scheme:

$$(R)SO_4 + CH_4 = (R)S + CO_2 + 2H_2O$$

This would make a complete cycle, and the result is always CO_2!

The oil itself is not necessarily changed; we only get $CO_2 + N$ back instead of air. If the acids should attack the oil, resinous and asphaltic products would be produced which can also remain behind in the sand. Possibly, however, only mineral carbonates and sulfates are changed and there is no reaction which affects the oil.

This problem is very important, for the question is whether oxygen in the sand sets up reactions that may clog the pores.

---

* Marland Refining Co.

Handling Recirculated Gas

By R. D. Gibbs,* Compton, Calif., and C. C. Taylor, Santa Fé Springs, Calif.

(Fort Worth Meeting, October, 1927)

The gas-lift, or circulation of gas for the production of crude oil, now includes the gas operator in field production activities to a greater extent than ever before. It is the purpose of this paper to show the scope of his activities and to discuss the various means of handling and treating the large quantities of gas which are now of a somewhat different nature than formerly. The extent of the stripping action of circulating gas on oil must be discussed, as this can be governed somewhat by the method of treatment of the recirculated gas.

Change in Gas-decline Curve under Circulation

Before the advent of the gas-lift, the gas-production curve of a field showed a peak during the flush production with a rapid decline as the wells were put on the pump and then a long steady decline curve of a relatively small volume of rich gas for the life of the field. Under the gas-lift method of production, instead of having the sharp decline at the end of the flush production period, sufficient circulating gas to keep up the required total gas-oil ratio would be turned to the wells. The gas-production curve then assumes a long gradual decline, giving a large volume of gas for treatment for several years to come.

The gas-decline curve will not follow that of the oil, as the lowering of the rock pressure by the steady production of oil and gas from the sand will make it necessary to continue using the large tubing and to circulate large volumes of gas in order to keep the back-pressure against the sands as low as possible.

A Complicated Distributing System

In tracing the flow of the gas from the time it leaves the well until it again enters through the casinghead, under high pressure, we get a very good idea of the complex distributing and regulating system that must be installed and the large treating and compression plants that are necessary (see Fig. 1).

Gas traps must be large enough to efficiently separate large quantities of gas and oil and should be elevated sufficiently to enable the oil, if

* Union Oil Co.

being produced steadily, to flow to the gage tanks under its own head. Traps equipped with automatic control valves are very satisfactory, as line pressure is practically maintained in the trap except when the heading may require more pressure to force the oil into the tanks. The elevation of gas traps and their operation under low pressure serves the double purpose of aiding in the circulation of the well by reducing tubing pressure and also aids in the conservation of the gasoline vapors that would otherwise be lost as tank vapors.

Gas gathering and distributing lines should be large enough to cut down line drop to a reasonable amount. The elimination of all possible pressure drop is very important. Instead of handling large quantities of gas during the flush production period only, the gas-lift method of production insures large volumes of gas over a much longer period of time. The cost of large lines is soon paid for by the saving of compression, which would otherwise be necessary in order to offset the line drop.

Gas-lift requirements have made necessary the development of more accurate regulating and volume-control devices. Keeping a constant pressure and an adequate volume of gas at important points in the system presents no simple problem. In most fields a continuous supply of excess gas is being sold or blown to the air. A back-pressure regulator at this point occupies the key position in the regulating system, as it insures the required pressure and volume throughout the entire system. Where there is any possibility of the demand for circulating gas and fuel, etc. exceeding the total amount returned from the field, an emergency line from some outside source should be connected into the system through a regulator that will open when the pressure drops below a certain point.

Meters should be installed on the gas lines to and from each well and to and from any point in the system where shrinkage is likely to occur. In this way, an intelligent gas balance can be made each day.

Surging of the gas from the field which is caused by any heading of the individual wells causes trouble in the compressor and absorption plants. This is usually controlled by efficient operation of the wells, except in fields where the water cut is high. Unless tubing sizes can be increased with additional water content, heading cannot be avoided.

Lean Gas for Treatment

Although the total yield of gasoline from circulated wells is much more than could be obtained under other operation, the amount per thousand cubic feet is always less. This calls for increased proportional absorber capacity in the absorption plants. The gasoline content of the wet gas will vary with the total gas-oil ratio. This was shown by

plotting curves with data from several leases in the Dominguez field (Fig. 2).

Stripping Action of Circulating Gas on the Oil

Much discussion has arisen regarding the increased natural gasoline production from a field that is being operated by gas-lift. There seems to be considerable difference of opinion as to whether this gasoline, if

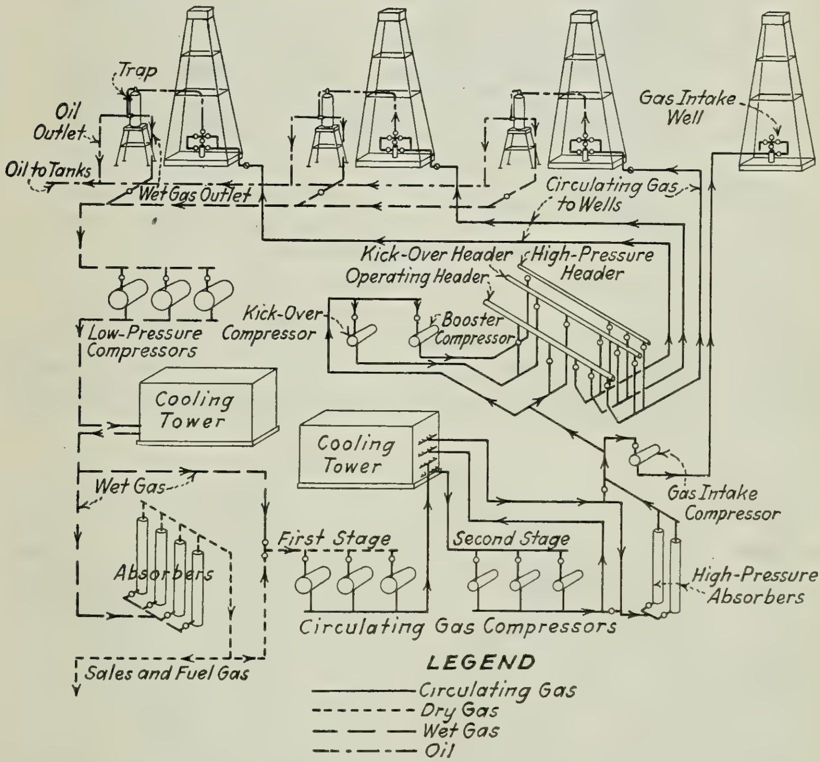


Fig. 1.—Flow sheet of gas-lift system.

left in the oil, would reach the refinery stills or would evaporate from the oil in transit and storage; thus representing a true saving if extracted in the natural-gasoline plants.

It would be supposed that the extractable gasoline in a formation gas would be in equilibrium with the crude oil from which it originated, and that the introduction of dry gas and the enrichment of that gas with further extractable gasoline would include gasoline fractions of a higher boiling range. In plotting gallons of gasoline to total barrels of oil and gasoline produced in several fields, the curve follows very closely the gas-circulation curve for the same field: for example, in the Richfield

district we find about a 50 per cent. increase in gallons of gasoline produced per barrel of oil and gasoline, which would indicate that some of the higher boiling gasoline fractions were being included in the gas (see Figs. 3–6).

The estimated production of figures for the Southern Division of the Union Oil Co. of California, from July 1, 1925, to June 30, 1926, which

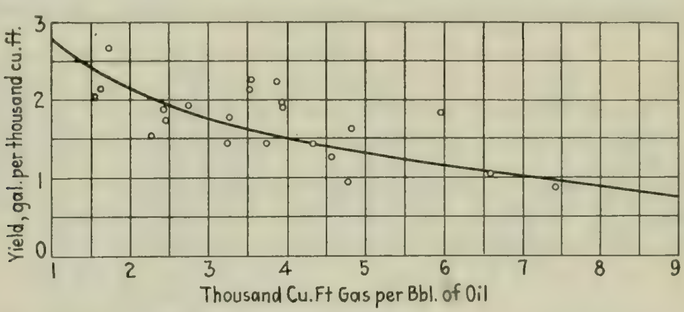


Fig. 2.—Relation of gasoline content of gas to gas-oil ratio.

were made up from normal decline curves, showed a natural gasoline recovery of 7.5 bbl. per 100 bbl. of oil. Gas-lift method of operation was used extensively and the actual production was 9.6 bbl. per 100 bbl. of oil.

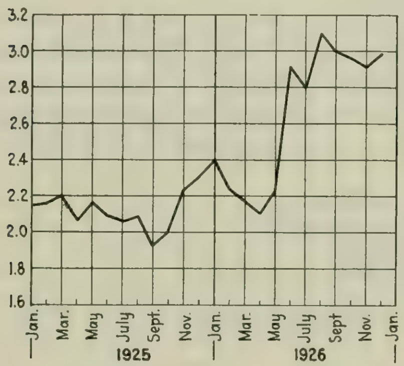


Fig. 3.—Ratio of gallons of gasoline to total barrels of oil and gasoline produced, Richfield district.

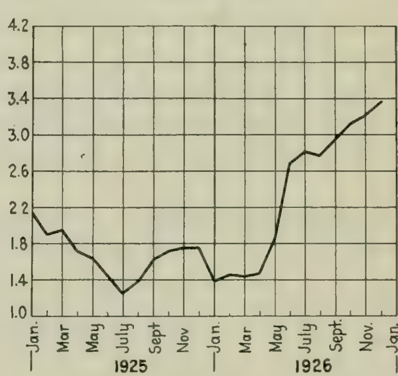


Fig. 4.—Ratio of gallons of gasoline to total barrels of oil and gasoline produced, Huntington Beach district.

Tests of oil from some wells have shown a lower gravity after the wells were put on circulation; others have remained practically the same. The gasoline content of the gas will vary considerably with trap pressures, as is shown by the curve in Fig. 7. The change in pressures may have some bearing on these discrepancies. Any increase in the percentage of emulsion might also affect it.

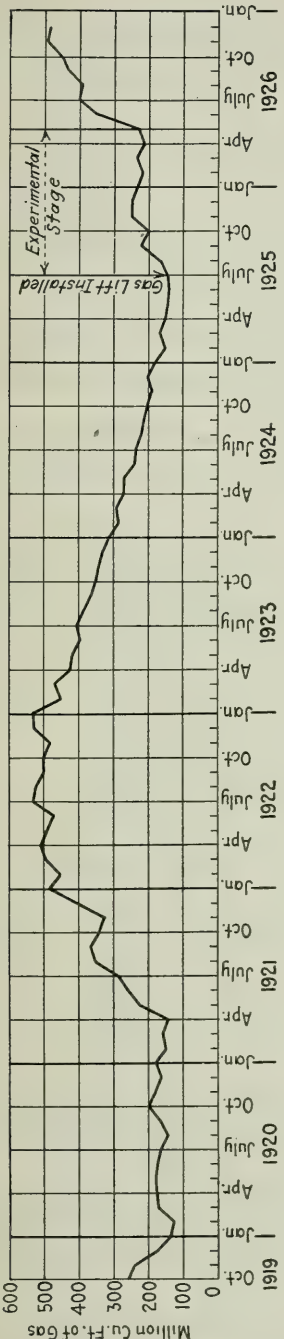


FIG. 5.—GROSS GAS PRODUCTION, RICHFIELD DISTRICT.

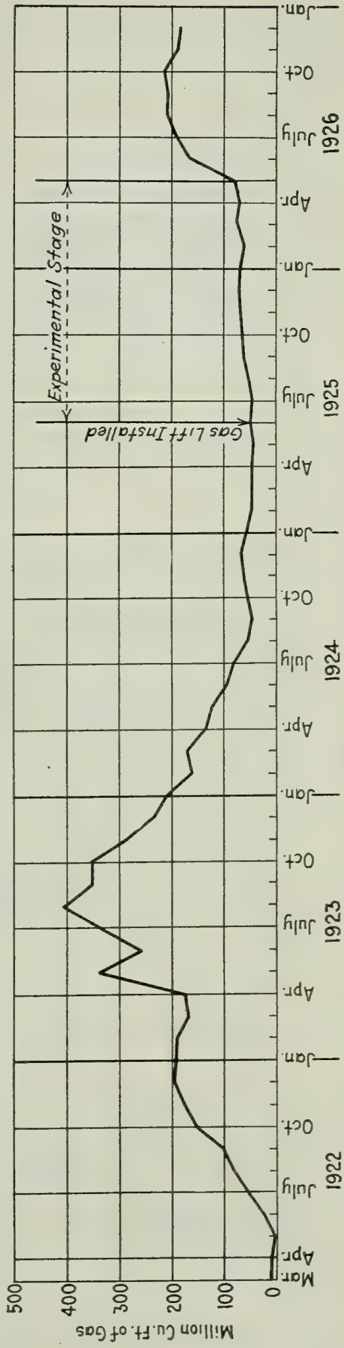


FIG. 6.—GROSS GAS PRODUCTION, HUNTINGTON BEACH DISTRICT.

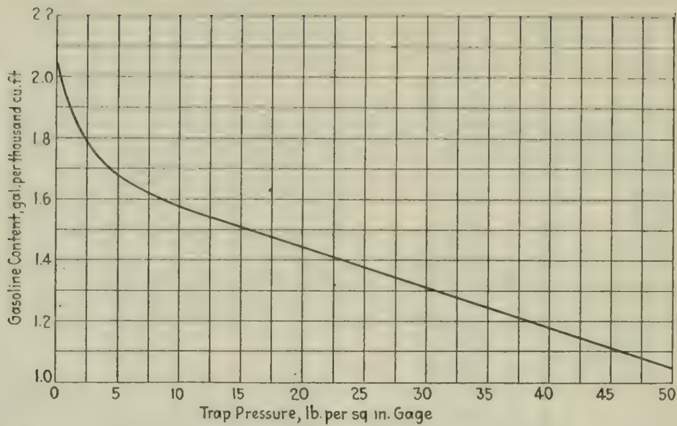


FIG. 7.—AVERAGE DECREASE IN GASOLINE CONTENT OF GAS DUE TO INCREASED TRAP PRESSURE, ON NINE WELLS IN THE BREA DISTRICT, CALIFORNIA.

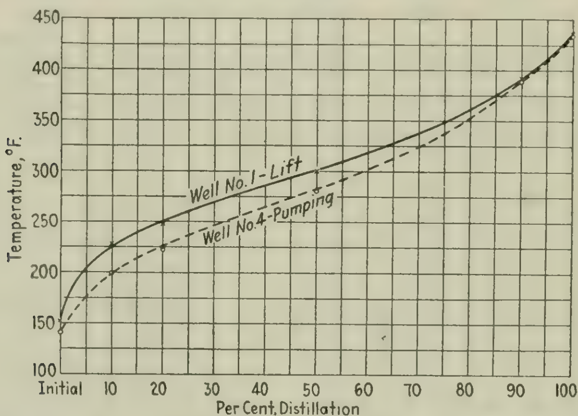


FIG. 8.—ENGLER DISTILLATION OF GASOLINE FROM CRUDE OIL, WELLS 1 AND 4.

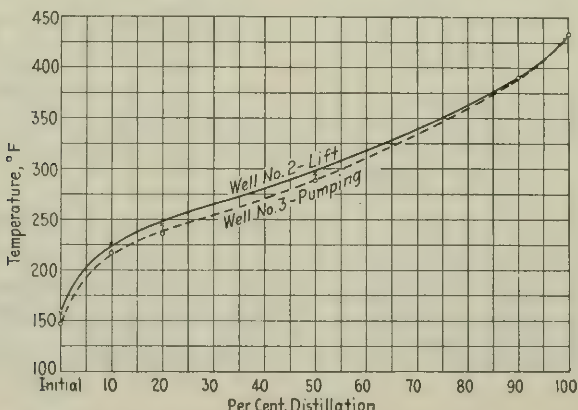


FIG. 9.—ENGLER DISTILLATION OF GASOLINE FROM CRUDE OIL, WELLS 2 AND 3.

In order to obtain more accurate information on this subject, tests were run on a group of wells in one of our districts. Four wells, of comparable physical characteristics were selected and tested over a period of 24 hr. Two of these wells were gas-lift producers, one being a flowing

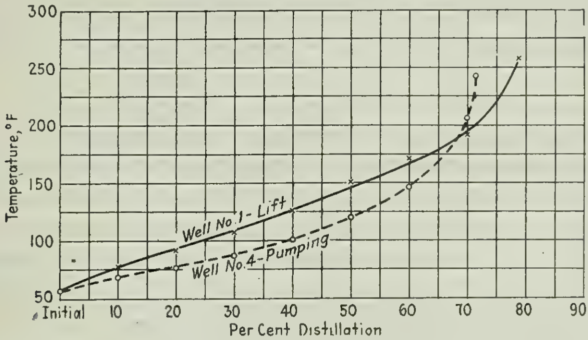


FIG. 10.—ENGLER DISTILLATION OF GASOLINE FROM LARGE CHARCOAL TUBES, WELLS 1 AND 4.

well and the other a pumper. Gas volumes were measured and tested for gasoline content. Crude samples were taken from the traps and tanks and distilled; Engler distillations and vapor-pressure tests were made on the condensates. Comparison of the test data gives the results

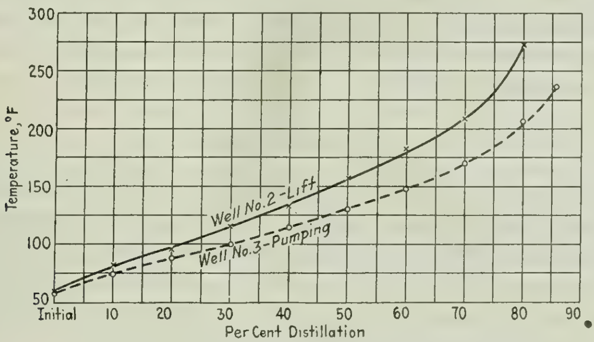


FIG. 11.—ENGLER DISTILLATION OF GASOLINE FROM LARGE CHARCOAL TUBES, WELLS 2 AND 3.

that might be expected (Figs. 8–11). The additional amounts of natural gasoline from the gas-lift wells check closely the amount of gasoline stripped from the oil as disclosed by distillation of the oil samples. Crude samples from the tanks taken after the oil had stood in the tanks for 24 hr. showed no appreciable loss over that period of time.

NATURAL-GASOLINE PLANTS

In deciding upon the most profitable installation of natural-gasoline extraction equipment, many factors should be taken into consideration.

Trap pressures, gravity of the oil, condition of the gage and storage tanks, distance from the refinery and the number of times the oil is handled en route, elapsed time between its production and its arrival at the refinery stills and the demand for natural gasoline are all influences that should be given careful consideration. The amount of stabilizing done in the absorption plant and the method of transporting gasoline also enter into the problem.

If one wishes to have the proverbial "bird in the hand" safe in the gasoline-storage tanks, there must be an absorption plant of sufficient size to treat all of the gas efficiently. All gas from the low-stage compressors will go directly to the absorbers, the circulating compressor plant and the various fuel lines, etc. being supplied with gas from the absorber discharge With dry-gas circulation aftercooler coils need not be installed in th circulating compressor plant-cooling tower. Circulation of a well with hot gas is considered a decided advantage. In addition to reducing paraffin troubles, it also tends to reduce the viscosity of the oil.

If it is best to hold down the amount of natural gasoline produced per barrel of oil, the compressor plant can be connected for either partial or entire wet-gas circulation. With ample intercooler and aftercooler coils, a 300-lb. compressor plant operating on wet gas should extract an appreciable amount of the condensable gasoline. This gasoline is of a fairly stable nature and can be used to good advantage for blending with the absorption gasoline. With the usual hook-up, the compressor-plant intake does not have to stand the effects of the absorber pressure drop if wet-gas circulation is used.

Conclusion

The handling and treating of gas from the field operated by gas-lift presents many interesting problems. Each new field brings new conditions to be met and difficulties to be overcome. It is only by a persistent study of these conditions and a definite understanding of the governing factors that we can arrive at the most profitable method of operation.

DISCUSSION

J. M. Lovejoy,* Tulsa, Okla.—Most of us in the Mid-Continent do not thoroughly understand or know what is going on in California. I am impressed with the similarity of our hook-ups to those in California.

A. C. Rubel,† Compton, Calif.—This paper carries on a little further than we petroleum engineers usually go. It really gets into the realm of gas engineering. As yet, we really know very little regarding the relative importance of circulating wet or dry gas. It is largely a question of plant capacity and considerations as to the relative value of the gasoline produced in the plant or as it accompanies the oil to the refinery.

---

* Vice President,Amerada Petroleum Corpn.

† Petroleum Engineer, Uinon Oil Co. of California.

All of our experience indicates that the stripping of gasoline from the fluid should result in a loss of gravity. In some cases we are unable to reconcile it entirely with the indicated loss of gravity. Most of our traps have been operated at a pressure of 30 lb. There is a tank loss which represents gasoline held in solution, or carried out by the gas given up between 30 lb. and atmosphere.

Unfortunately, we are not as far advanced in the art of protecting our field storage as in the Mid-Continent area. Therefore, as this paper says, we have adopted the policy that "a bird in the hand is worth two in the bush" and we are attempting to recover our gasoline where we are sure we can get it.

W. V. Vietti,* Fort Worth, Texas.—This paper suggests certain economies to be obtained by the collection of data and their interpretation.

First, consider the advisability of holding 25 to 30 lb. back-pressure on the trap. After Mr. Taylor held 30 lb. pressure on his traps he still had enough gasoline to run the gas through a gasoline plant. It is not absolutely sure that this will happen in all cases. The crudes produced in the Los Angeles Basin are at a high temperature and absorption of gasoline from the vapor state will not be as efficient as when lower trap temperatures exist. Absorption also depends on the character of the oil and gas. There are cases where the holding of back-pressure on the trap will decrease the gasoline content of the gas down to a point where the gasoline plant can be eliminated.

Second, when a plant is compressing gas to 300 lb. and sending the gas back to flow a well, it should be possible to run the compressed gas through a refrigeration plant and get out a lot of the gasoline. This would eliminate the need for an absorption plant which requires a considerable investment and an appreciable operating cost.

The holding of back-pressures on traps and the use of refrigeration should accomplish much the same results as an absorption plant, without the added costs.

C. C. Taylor.†—I should have said our principal reason for this is caused by the gas-lift problem. We find it necessary, with a low rock pressure such as we have in some cases, to carry a low trap pressure to get maximum production from the well. That is the reason we have gone so extensively into the trap pressures.

A. W. Peake,† Casper, Wyom.—I would like to ask about the relative investment and operating cost of recirculating plants. As I remember it, when the casinghead business started, straight compression process was used; then high- and low-pressure absorption. Since the gas-lift has come into extensive use we have low-pressure absorption plants which have gone back to repressuring the gas. What is the relative cost of investment and operation of the straight compression plant for extracting the gasoline and redelivering the gas versus low-pressure absorption plant and then repressuring?

C. C. Taylor.—In most of the fields on gas-lift in California, we have large absorption plants which were built before the advent of the gas-lift, and we have in some cases added to these plants. We are drawing the wet gas and circulating it to increase the natural gasoline production. I also would like information on the comparative cost of the two systems.

E. Kaye,‡ Tulsa, Okla.—The question propounded is not taken into consideration in every case. One cannot very well build a repressuring plant of 25,000,000 ft. capacity when only 10,000,000 ft. are needed for the gas-lift. I think any gas that will test 1½ gal. of gasoline will justify a straight compression system like that in the Seminole. There the gas is treated with relative efficiency at less cost than at some absorption plants. Obviously, where all the gas can be treated in a compression unit required for the lift, other means of extraction are not justified.

---

* Marland Oil Co. of Texas.
† Midwest Refining Co.
‡ Skelly Oil Co.

W. V. Vietti.—The point I wish to bring up is that an operator having two or three wells, probably having four or five million feet of gas a day, would find it advisable to put in a small refrigeration plant and recover some gasoline and hold high back-pressure on his traps to recover still more. We know by experiment that we have increased the gravity of our crude in this way. The crude and gas characteristics must be considered.

The Union Oil Co. in California can well afford to put in gasoline absorption plants if there is 1½ gal. of gasoline per thousand feet left after holding 30 lb. pressure on the traps, but a comparable result might have been obtained by refrigerating after the second-stage compression.

A. W. Peake.—If 30 lb. back-pressure is held on the trap to increase the gravity of the oil, how much of that oil reaches the refiner? Isn't "a bird in the hand worth two in the bush?"

A. C. Rubel.—The very reason we have gone to the gas-lift and also to low trap pressure is to effect the point that has been made. We do believe "a bird in the hand is worth two in the bush," and we also believe that there is very little to be gained by putting in an elaborate recovery system in the field and then allowing the vapors to be dissipated elsewhere. Until we are completely equipped from the gas trap to the refinery still, we believe it well to get the gasoline while the getting is good.

A. W. Peake.—From very extensive field tests on this problem, I agree 100 per cent. with Mr. Rubel.

J. R. McWilliams,* Tulsa, Okla.—In the California experiments, was any difference noted in the cost on compressors and other equipment when the change was made from dry to wet gas; and if so, of what nature?

C. C. Taylor.—We have not been running on wet gas long enough to determine this.

J. M. Lovejoy.—Absorption units are made so portable now that it is quite possible to use one in connection with a gas-lift plant for six or eight months and then move it on to the next lease. Our problem here is different from that in California. We can put in two or three portable units, get the flush production and then move them on. My impression is that compression equipment of the same type would be more expensive.

* Skelly Oil Co.

Mechanical Installations of the Gas-lift in Texas Outside the Gulf Coast Region

By E. V. Foran,* Fort Worth, Texas

(Fort Worth Meeting, October, 1927)

There are many factors which control the ultimate production of oil and gas from a producing formation and the rate at which this production is obtained from any of the producing wells in the formation. The most important of these, and the one over which the greatest control can be exercised, is the differential pressure existing between the formation and the well bore. In producing any well by means of the gas-lift, it may be possible to change the flow tubing in a number of ways or vary the volume of circulating gas or air used for flowing the well, but if these operations, regardless of their magnitude, do not change the differential pressure between the producing sand and the well bore, they will in no way change the production of the well. If this statement is accepted as a fact, then all gas-lift or air-lift installations should be designed with but one object in view; namely, a means by which we can economically control very wide ranges of differential pressures between the formation and the well bore.

Factors of Production

In gas-lift production from any given formation, there are four major factors which govern the magnitude of the differential: (1) the depth of the well; (2) type and size of flow tubing; (3) volume of the circulating air or gas, and (4) physical properties of the oil-gas mixture after it has reached the well. The first of these factors is uncontrollable and does not vary. The other three are controllable within certain limits.

The degree to which the last three factors can be controlled will entirely govern the length of life of the well while on the lift, the lifting cost, and the daily production. It will also govern to some extent the ultimate production from the wells or leases producing by this method. These four factors will be discussed in detail in another part of this paper.

Before proceeding further, a review of the present general practice in Texas, elsewhere than in the Gulf Coast region, will be given.

---

* Production Engineer, Marland Oil Co. of Texas.

Panhandle Area

Nearly all of the gas-lift wells in this area are from 2900 to 3200 ft. deep. The tubing sizes in the wells vary from 2½ in. to a maximum of 4½ in., depending on the size of the well. Due to the extremely rapid deposition of paraffin in the flow tubing, it is necessary to clean the tubing daily, or every other day, by means of a mechanical scraper, the operation of which has been described in detail by Bennett and Sclater.[1]

Mixed flow strings are not used in the Panhandle area, as they would require a different scraper for each section of the tubing where a change in the diameter occurs. This to a certain degree limits the efficiency obtainable, as the entire 3000 ft., more or less, of tubing is of the same diameter and therefore will have a widely variable ratio of velocity between the bottom and top of the well. For the most efficient operations it would seem that the velocity ratio of the gas-oil mixture throughout the tubing should be kept as nearly constant as possible. This point will be further discussed in another part of this paper.

The position of the bottom of the tubing varies in different wells. In some cases it is kept at 600 ft. above the top of the producing formation, and in other cases, it is set at a point just above the top of the producing formation. It is believed that if the tubing were set at certain points within these ranges, maximum efficiency would result.

The required working input pressures to flow wells in the Panhandle varies from approximately 100 to 225 lb. per sq. in. Under these conditions, the gross gas-oil ratio varies from 2200 to 3500 cu. ft. per bbl. of oil. The net gas-oil ratio from the sand varies from 200 to 600 cu. ft. per bbl. The starting pressures required on these wells vary from 250 to 500 lb. per sq. in.

The power for compression used in the Panhandle area is furnished by gas engines on electric motors. The gas is separated from the traps and passed through gasoline compression plants; then into the high-pressure stations. In some cases dry natural gas is compressed to the required pressure and transmitted to the lift wells. The rock pressures in the Panhandle lift wells vary from approximately 175 to 400 lb. per sq. in.

West Texas Area

Gas-lift methods of production in the new fields of West Texas are occupying considerable attention. During the last six months, the gas-lift has been employed in the Crane-Upton County area by the Humble, Tidal, Gulf, Marland, Simms, Landreth and other companies. In the Howard County fields, some preliminary experiments have been conducted but there are, as yet, no permanent plants. In the Noodle Creek

[1] E. O. Bennett and K. C. Sclater: Some New Aspects of the Gas-lift. Petroleum Development and Technology in 1926, 115.

field in Jones County, the Marland Oil Co. has been operating by gas-lift methods during the last eight months.

In the McCamey area, both the Marland and Roxana companies have tried to overcome the difficulties encountered in handling the corrosive H_2S gases, but success has been limited and marked by frequent interruptions of the operations of the plants. The production in the McCamey area comes from lime at about 2100 to 2300 ft. The tubing used in these wells is 2½ and 3 in. It is usually set 300 or 400 ft. off bottom and the input air pressure at the casinghead varies from 160 to 200 lb. Air is used as insufficient gas is available for this purpose. The corrosive action of the air and sulfur gases is so severe that tubing must be replaced in these wells every six weeks. This gas cannot be used for the engines as it will completely burn through the piston head in three or four months.

The Church and Fields University Pool in Crane County is probably the most active area of gas-lift operations in Texas, at the present time. The production from this area comes from a lime formation from 2600 to 2700 ft. in depth.

One of the outstanding features of the operations in this pool is the type of surface equipment used. All of the plants are equipped with compressors capable of delivering gas for starting pressures as high as 600 lb. and in some cases to 1000 lb. Volume-control meters are installed in nearly all cases where gas is being delivered from a high-pressure header to several wells which require different input pressures. Air is used to flow the wells, as there is insufficient gas for this purpose. Not all of the gas-lift wells are equipped with meters to measure the output gas, although there is a meter on each input well. This, of course, makes it impossible to say just what the net gas-oil ratio is.

The tubing sizes vary from 2½ to 4 in., depending on the size of the wells. The gross gas-oil ratio in this pool seems to be very low, the majority of the wells averaging from 700 to 1100 cu. ft. per bbl. The input casinghead pressures on the other hand are rather high, averaging from 150 to 215 lb. Some of the wells making around 400 bbl. have working pressures as high as 175 lb. per sq. in.

The tubing position in these wells in most cases ranges from 250 ft. to as high as 550 ft. off bottom. This is due in part to the high starting pressures off bottom and in other cases it is based upon the supposition that the most efficient tubing position for a gas-lift well is at some critical point which may be anywhere from the top of the pay to a point several hundred feet up the casing. The results in this field show possibilities of long life for the gas-lift, if it will be possible to reduce the working pressures against the face of the producing sand as the rock pressure becomes depleted.

In the Noodle Creek field in Jones County, the Marland Oil Co. has made a radical departure from conventional tubing sizes and arrange-

ments as well as plant design and methods of gas recirculation. Due to the curtailment in drilling operations in March, 1927, only one well was put on gas-lift production. This was a 1400-bbl. well and was placed on the lift Feb. 4, 1927, 12 days after the well was completed. The production in the pool is from a lime formation at 2510 ft. The initial rock pressure of this field was abnormally low, showing approximately 330 lb. per sq. in.

A 4-in. flow tubing was specified for the well but was unobtainable at the time, and a $5\frac{3}{16}$-in. casing was used as a flow string. The well was completed with 8-in. casing. Recording meters for gas measurements and pressures were installed at both input and discharge sides of the well. Air was forced down the 8-in. casing and the oil flowed up the $5\frac{3}{16}$-in. tubing in violent heads every 55 min. at the rate of 780 bbl. per day. This was unsatisfactory and a $2\frac{1}{2}$-in. tubing was run inside of the $5\frac{3}{16}$-in.; the gas was forced down the $2\frac{1}{2}$-in. tubing and the oil produced between the $2\frac{1}{2}$ and the $5\frac{3}{16}$-in. The result was a steady flow at 1085 bbl. daily with a gross gas-oil ratio of 905 cu. ft. per bbl. and the input pressure at 195 lb.

This arrangement was considered satisfactory. The following week additional air was forced into the well and the input pressure dropped to 160 lb. and the well increased its production for a short time. After the well had been on the air-lift three months, the daily production fell below 500 bbl. and the input pressure had dropped to 124 lb.; the lifting gas-oil ratio increased to 1600 cu. ft. per bbl. The well showed indications that it could not flow much longer under the 124-lb. input pressure, due to the rapid pressure depletion in the sand on account of this well being offset by three other producers.

At this point it was decided that a radical change in both the tubing arrangement and compressors would have to be made in order to obtain the desired lower input pressure.

The high-pressure cylinder of a two-stage tandem-driven compressor was replaced by a low-pressure cylinder and the volumetric capacity of the compressor was doubled. Both the $5\frac{3}{16}$ and $2\frac{1}{2}$-in. tubing were pulled and a mixed string consisting of 275 ft. of 3-in. tubing as the lower part, and 2226 ft. of $5\frac{3}{16}$-in. casing as the upper part of the tubing was run in the well. The total tubing length was 2501 ft. This placed the bottom of the tubing 8 ft. above the top of the sand.

The well was then put on production and the input air pressure required to flow it was only 60 lb. Six pounds back-pressure was indicated on the casinghead. This low pressure against the face of the sand resulted in an increase in the effective drainage area of this well, which, in turn, resulted in a decline rate much slower than before the change was made.

Although the increased volume of input air on single-stage compression gave remarkable results in contrast to those observed before the tubing change was made, it also presented some disadvantages, the greatest of which was the reduction of the gravity of the oil from 39.5° to 38° A. P. I. due to increased gasoline losses which were escaping to the air as there was no gasoline plant available to recover the vapors which tested 1.2 gal. of gasoline per 1000 cu. ft. The daily popoff to the air was 950,000 cu. ft. This indicated a loss of 1140 gal. of gasoline daily.

It was then decided to recirculate the output air-gas mixture from the well and allow any condensate which might occur after compression to return to the well instead of installing condensing coils following the compressor discharge. This process resulted in an immediate rise in the gravity of the oil from 38° to 41° A. P. I. and an increase of 24 bbl. of oil per day, which represented the vapor losses in the air-gas mixture formerly escaping to the air. The gas was separated at the trap under a pressure of 7 lb. and delivered to the compressor intake at 5 lb. above atmosphere. This increased the compressor output 25 per cent. above the free-air capacity and resulted in a lower input pressure on the well. It is, therefore, apparent that this practice may open new possibilities to gas-lift operations which will result in a higher over-all efficiency of ultimate production. This can be attained through the installation of a tubing pattern of such sizes and arrangement that wells producing up to 1000 bbl. daily and at depths up to 3000 ft. may be flowed at pressures which will require only single-stage compression.

Depth of Wells

Gas-lift practice in Texas, other than the Gulf Coast region, is confined to wells whose depths vary from 800 to 3200 ft. There are some wells of less than 800 ft. on gas-lift but they are unimportant and will not be discussed in this paper. Since the depth of a gas-lift well is a vital factor effecting the formational differential and cannot be changed, its influence must be compensated through a variation of the remaining three factors.

Type and Size of Flow Tubing

In analyzing the present gas-lift practice in Texas, it appears that every installation is of a somewhat different type. The trend of operations at the present time seems to be toward those installations which are capable of lifting a barrel of oil to the surface with the lowest gross gas-oil ratio. At first thought, a low gross gas-oil ratio would seem to be highly desirable, and should be indicative of the efficiency of the installation, but if the gas-lift method of production is to occupy a prominent position in the production life of a well or lease, the measure

of efficiency must be reduced to lifting costs per barrel in dollars and cents and the effect on ultimate production rather than the control of the gross gas-oil ratio. Burnett[2] states:

> Mechanically the gas-lift is operating as maximum efficiency when it produces the most oil with the least amount of gas. It may be, however, that increase in volume of gas supplied will result in a decrease of gas production from the well itself and from the standpoint of ultimate yield; this would in most cases be preferable to the mechanically more efficient condition.
>
> Moreover, an increase in gas volume may substantially increase the oil production and although that increase of gas may be out of proportion to the increased production, the latter may yet be sufficient to justify the poorer efficiency. Cost per barrel produced is the determining factor rather than the mechanical efficiency.

The pressure exerted on the face of a producing sand of a gas-lift well is equal to the pressure due to the effective weight of the flowing column of the liquid-gas mixture plus the pressure required to overcome the frictional resistance of this mixture to flow.

This pressure may be reduced through increased aeration of the fluid mixture provided the tubing has sufficient cross-section area to accommodate the increased flow of gas without requiring a high velocity. Under these conditions the loss in weight of the flowing column due to aeration is much greater than the increase in friction caused by the greater volume of gas flowing with the oil. The result is an over-all drop in pressure at the bottom of the tubing. This constitutes the principal advantage of large tubing over small tubing in cases where the rock pressure is subnormal.

In the use of large flow tubing it may be reasoned that the velocity of the gas in the lower portion of the tubing might be so slow, due to the higher pressure of the gas in this portion, that it might not disseminate the oil properly and thus cause heading and "slippage." This is quite likely to happen unless the lower portion of the tubing is reduced to such a size that the initial velocity of the gas-oil mixture will produce a steady flow. The length of the reduced portion need not be more than 10 or 15 per cent. of the total length of the flow string.

It is apparent that if the maximum size of tubing that can be used in a well is efficient for low-pressure work it means that one tubing installation is all that is necessary during the gas-lift life of the well. This is explained by the fact that when a well is larger than 1000 bbl. daily it may be flowed by two-stage compression at low gross ratios, and on falling below 1000 bbl. daily, the high-pressure cylinders of the compressors may be replaced by low cylinders and low-pressure flowing accomplished. Since the surface flow lines and trap installations have been given prominent mention in describing gas-lift operations during the last year, they will not be discussed other than to say that the trap should be as close as

[2] Robert Burnett: Air andGas -lift Methods and Equipment. *Oil Weekly* (Aug. 19, 1927).

possible to the well and the lead lines be equipped with long radius ells or bends wherever a change in the direction of flow is required. If recirculation of the wet gas is desired, the gas line from the trap to the compressor intake should be large enough to carry the gas with a minimum of frictional losses.

Volume of Circulating Gas or Air

As previously stated, if the flow tubing is of sufficient cross-sectional area, the volume of circulating gas may be increased until the working pressure against the face of the producing sand has declined to the point where it requires the least volume of formational gas per barrel of oil produced. If the gas is separated in the trap under pressure, it may be returned to the compressor at pressures above atmosphere and result in a larger volume of circulating gas and a more efficient flowing condition. With any given tubing sizes and arrangement the volume of circulating gas required to do the best work can be quickly determined by simply increasing or decreasing the compressor output and noting the results.

Physical Properties of the Gas-oil Mixture after It Has Reached the Well

Immediately after the oil-gas mixture from the formation enters the well it comes in contact with additional gas that may or may not be saturated with the volatile hydrocarbon vapors. If the input gas (gas or air) is not saturated it immediately absorbs the gasoline vapors from the oil and results in a progressively higher viscosity of the oil as the pressure drops on approaching the surface. It also increases the rate of

Table 1.—*Daily Operating Characteristics, Mason Well No. 3, Marland Oil Co.*

	Daily Production, Barrels	Input Pressure, Pounds	Input Gas, Cu. Ft.	Output Gas, Cu. Ft.	Gross Gas, Cu. Ft. Per Bbl.	Net Gas, Cu. Ft. Per Bbl.	A. P. I. Gravity	
Feb. 10	1,084	195	786,000	981,000	905	180	40.0	Used air for input.
Mar. 10	785	143	707,000	952,000	1,228	245	39.8	Used air for input.
Apr. 10	629	127	724,000	978,000	1,555	404	39.7	Used air for input.
May 10	484	120	731,000	947,000	1,956	446	39.5	Tubing compression changed May 13.
June 10	402	63	846,000	1,016,000	2,521	416	38.0	Air input single-stage compression.
July 10	364	60	947,000	1,024,000	2,812	212	41.0	Recirculation of wet gas at 5 lb. intake pressure at compressor.
Aug. 10	321	55	1,065,000	1,150,000	3,616	265	41.0	No change in operation.
Sept. 10	315	53	970,000	1,045,000	3,318	238	41.0	No change in operation.

paraffin deposition on approaching the surface. When wet gas is recirculated by means of single-stage compression and all of the vapors and condensate allowed to return to the well, these conditions cannot happen. It is, therefore, well to state at this time that gasoline plants that take the gasoline out of recirculated gas are a serious detriment to gas-lift operations. They should be permitted to take the gasoline out of only that portion of the total wet gas production which escapes to the air. A single-stage compression plant which returns all vapors and condensate to the well accomplishes the same work as the gasoline plant without the first cost or maintenance of the gasoline plant. The recirculation of the wet gas merely stops the separation of gasoline from the oil and delivers it to the tanks at the maximum gravity possible.

The summary in Table 1 shows the comparative results on a well in the Noodle Creek field, Jones County, which was changed from two-stage compression flowing at moderate pressures to single-stage flowing at low pressures. This well has been surrounded during its entire lift by pumping wells, as no wells in this field have ever flowed even when first completed. The rock pressure was very low and the formational gas-oil ratio was only 150 cu. ft. per bbl. on completion of the well.

DISCUSSION

C. V. Millikan,* Tulsa, Okla.—One point mentioned was that reducing the pressure at the sand reduced the gas-oil ratio. Do you find that true in most of your installations?

E. V. Foran.—We did not have orifice meters on both the input and output of all of our gas-lift equipment. In the particular case mentioned I assume that the decrease in gas-oil ratio was occasioned by releasing the gas from doing some of the lifting work.

C. V. Millikan.— In most of our gas-lift installations at Seminole, when we increase the production there is a decrease in the gas-oil ratio. If we run the tubing while the well is still flowing and inject gas we find that if the production is not changed there is little change in the gas-oil ratio. If we decrease the production—that is, if we run the tubing too quickly—we obtain an increase in gas-oil ratio. I assume we have increased the back pressure on the sand.

That brings up the debatable practice of putting pressure on the trap. It is the general practice at Seminole to carry 5 to 12 lb. on the gas trap at the well. In a large number of cases where pressure was put on the trap the natural gas-oil ratio was decreased. On first thought those statements may appear to be contradictory, but we have another consideration—velocity.

There is a velocity which if exceeded decreases the efficiency of the lift and I believe that, because of the size of tubing to which we are limited, we obtain excessive velocities altogether too often, and that an increase in the pressure on the trap reduces velocity to a more efficient rate. The final result may be as Mr. Foran mentioned, that we have actually reduced the pressure on the sand instead of increasing it, as appears on first thought.

---

* Amerada Petroleum Corpn.

E. V. Foran.—I failed to mention the velocity at the bottom if the tubing is of the same size throughout. With 49 lb. intake and 13 lb. back-pressure, the ratio of the velocity between the bottom and top is only 2.5:1, a very low ratio in a well making 300 to 600 bbl. a day. The reason for the back-pressure held against the trap was, as Mr. Millikan stated, to reduce the velocity in the upper part of the tubing. This is the advantage of tapered over straight tubing.

H. P. Porter,* Tulsa, Okla.—What was the most economic velocity, in this particular case, at the bottom of the column?

E. V. Foran.—Our means of determining that is simply to increase or decrease the volume of input gas and note the results. It will be different in different wells. However, it can be determined by pinching or opening a valve, provided tubing is of maximum size. If all gas-lift wells are installed with maximum tubing size, that point can be determined by any field man.

H. P. Porter.—I referred to that particular well. I assume that you did calculate it and know what the velocity was?

E. V. Foran.—It was approximately 61 ft. per sec. at the bottom of the well and 80 ft. per sec. at the top. The reason for that was straight tubing. As soon as we had restricted the tubing the velocity actually was about 60 ft. per sec. to 81 ft. at the top—less than 2.5:1 ratio with straight tubing and very much less than 2:1 with tapered tubing.

R. Van A. Mills,† Bartlesville, Okla.—In the Salt Creek field, Wyoming, in 1922, Mr. Foran was one of the gas engineers for the Midwest Refining Co. At that time the Midwest Refining Co. and the Bureau of Mines were working together to conserve gas in that field. It was thus my privilege to work with Mr. Foran. We found that when certain wells were flowing through 2-in. tubing there existed a marked relationship between the lowest gas-oil ratio and the pressure in the flow string at the top of the well. To secure the lowest gas-oil ratio we had to maintain the lowest pressure in the flow string (2-in. tubing) at the top of the well. Under these conditions of lowest gas-oil ratio we also obtained the greatest gasoline content in the gas accompanying the oil. The gasoline content of the gas appeared to vary inversely as the gas-oil ratio. In other words, within certain limits, a reduction of 50 per cent. in the gas-oil ratio appeared to yield an approximate increase of 100 per cent. in the gasoline content of the gas accompanying the oil. This investigation was not completed when I left the Salt Creek field and I would like to ask Mr. Foran, first, if that relationship was found to hold true throughout all of the tests; and second, whether he has found that same relationship in his gas-lift work? Also, I would ask Mr. Foran whether beaning at the bottom of the tubing in flowing wells bears any relationship to his findings with combination tubing in the gas-lift work? If so, is it not possible that the use of combination tubing will offer one of the best means of conserving gas in flowing wells where we have flush production?

---

* Gypsy Oil & Gas Co.

† U. S. Bureau of Mines.

Mechanical Installations for Air-gas Lift in the Gulf Coast Area

By L. L. Brundred,* Los Angeles, Calif.

(Fort Worth Meeting, October, 1927)

The major portion of the production of the Gulf Coast area, represented by South Texas and South Louisiana, comes from the flanks of well-defined salt domes. This oil, containing an excellent lubricating stock, ranges from 17° to 28° Bé. gravity. Some lighter oil is encountered but the life of such fields is, in general, an open question. In fact, there are few light-gravity fields which have proved of much value.

In all of the fields water encroachment, or, more properly, water produced with the oil, is a vital factor. After the first head of high-pressure gas is removed, ever-increasing percentages of water appear, and naturally the life of the wells is materially affected thereby.

The sands are, as a rule, extremely fine, very soft, and must be carefully excluded from the hole by the use of fine screen to prevent sanding up. All sands are tipped at such extreme angles as to make coring essential for the location of water strata, oil-bearing sands and important shale beds. Even with modern coring, the correlation of logs is a difficult problem.

Due to the fact that the bulk of the oil is refined for its lubricating properties, little attention has been paid to losses by evaporation in the field. This is largely influenced by the fact that the major companies have set a price schedule, showing but two grades, "A" and "B." The average oil company, therefore, does not attempt to use the gas-lift but relies primarily on the air-lift and then only on wells considered to be particularly adapted to its use, namely those capable of producing large quantities of fluid and yet not having sufficient "kick" to flow.

Furthermore, as the gas contained in the reservoirs is mostly methane, such gas being very quickly vaporized and produced in large quantity in the early life of the fields, there is little gas left after the first flush flowing period of the wells. In fact, it is very generally conceded that gas is a precarious fuel to depend on in any of the coastal fields. This situation largely accounts for the fact that air, as the lifting medium, is almost universally used.

In the average field, wells are drilled on the flanks of the domes in close proximity to one another, largely on account of the extreme dips of the formation and "town lot" leases, and space to set up machinery and

* Consulting Petroleum Engineer.

other equipment is very restricted. Also, the swampy condition of the average field adds to the difficulty of securing good foundations without extreme expense.

Consideration must also be given to the relatively short life of any one producing horizon. It has often been pointed out that whatever oil is to be obtained from a given horizon must be produced before the expiration of a two-year period, as the increase in percentage of salt water will make production of the well from that particular zone highly unprofitable thereafter. To be sure, there are in most of the fields many additional zones to be called upon, so that wells are constantly being deepened or worked over to bring back their profitable production.

Steam as Motive Power

Expenditures of large sums for more or less permanent gas-lift equipment have been considered illogical. The average operator therefore considers quickness of installation, portability to a new field and salvage value rather than cheapness of fuel and other costs of operation. The direct result of this attitude is that steam-driven compressors have formed the greater part of all installations.

Another important factor influencing the use of steam is the necessity for fire protection in such closely drilled fields. For this purpose boilers with steam pressure constantly available must be erected. By the addition of one or more units to the boiler station, steam in sufficient quantities is available both for the compressors and for fire protection.

The coastal area is perhaps the most completely electrified oil-field section of the United States, in that high-tension power lines form a veritable network of connecting sources of electric power, at a very favorable rate to the consumer. Such rate is surprising in view of the fact that all generating plants are steam driven. The availability of this relatively cheap power accounts for some of the recent installations of compressors belted to electric motors. The cost of operation, however, is hardly comparable with units driven by gas or oil engines.

Practically all compressors installed to date, whether steam, electric, gas, or oil-driven have had displacements ranging from 300 to 500 cu. ft. per min., and little attempt has been made to centralize control in one large distributing plant serving a number of wells simultaneously. In fact, it was practically an accepted fact in this area that it was essential to have one compressor to one well. Also, little use has been made of the modern volume controllers for carefully apportioning the gas to each well. As a result there are practically none of the so-called "central plants" operating a number of wells either with the loop system or header control house located near the plant.

Efficiency Data Lacking

On account of the heavy type of oil produced, the large percentage of water present and the failure of the bulk of the oil companies to take advantage of the most modern methods, such as unrestricted flow pipes, traps set close to the derrick floor, and the use of volume controllers, little information as to the exact efficiency being obtained is available. In the few cases where this information is available, the results would seem to indicate that the wells in this area will require slightly higher circulated gas to oil ratios than that necessary in other fields. It must be said, however, that there is an insufficient number of installations where the input and output air is metered to make such a statement entirely conclusive.

Little attention has been paid to the Christmas tree installations, in that the bulk of the wells "on air" have used the original Christmas tree hook-up with which the wells were brought in. It followed that considerable difficulty was experienced in attempting to raise or lower tubing quickly as well as to start the wells on gas-lift by rocking. The work being considered largely experimental, few of the operators were willing to incur the expense of special gas-lift Christmas tree layouts.

The use of jets or other flow devices seems to be prevalent. Comparative data on the same well using first a flow device and later open-end tubing are not available and little experimental work of any kind has been conducted to date, due primarily to the present low price of oil.

Experiment Needed

Recent drilling has opened sands at a much greater depth than those encountered heretofore and the task of pumping these wells, especially with the high percentage of water present, has become a distinct problem. It is believed that gas-lift under proper control and with proper mechanical installations will, after considerable experimental work, prove to be of considerable aid in the solution of these problems. This area offers certain fundamental difficulties not encountered perhaps in any other district; therefore, only by experiment can the full value of this modern method of producing oil from deep sands be determined.

Mechanical Equipment of Air-gas Lifts in Oklahoma and Kansas Exclusive of Seminole

By Reid W. Bond,* Tulsa, Okla.

The gas-lift is a comparatively recent development in the Oklahoma and Kansas fields. It was used to some extent in the old Dilworth field several years ago, but the first extensive installations were made in the Tonkawa and Garber fields in Oklahoma early in the year 1926.

Compressor Equipment

During the early development of the system, the equipment used generally consisted of small tandem compressors of about 250 cu. ft. per min. displacement, driven by automotive-type gas engines, using a short belt drive. These compressors were first installed at the individual wells largely as an experiment.

After the experimental installations had proved the method a success, it was considered economically advisable to centralize the compressor equipment in strategically located stations. However, as the information in regard to "gas-lift flowing life" was anything but definite, and the most optimistic estimates in regard to it did not exceed six months, portability of equipment was still the first consideration in the minds of many operators, who continued to install small semi-portable compressors in their centralized stations.

As electric power became available in the fields, the electric motor came rapidly into use as the prime mover for the small compressors. The operating cost of this motor is greater than that of the automotive-type gas engine for the same power output, but the greater continuity of service tends to balance the extra cost.

Aside from the semi-portable units, a number of strictly portable compressors were used. These consisted of automotive-type gas engines direct connected to vertical compressors. The unit was assembled on one base and could be mounted on wheels or skids as desired. The chief objection to these, in the writer's opinion, was their small capacity—approximately 150 cu. ft. per min.—which made it necessary to use two, three, and sometimes more units per well, thus making the installation rather costly. However, they have been found valuable for test purposes and emergencies, where installation time is an important factor.

* Production Engineer, Roxana Petroleum Corpn.

When the compressors were first centralized, some operators decided to sacrifice portability in favor of larger volume per unit and installed duplex compressors, belt driven by slow-speed gas engines. This type did not prove very popular and comparatively few of them are in use. The present trend in large compressor equipment is the direct-connected duplex, driven by twin-cylinder gas engines. Probably the most common size is the 180-hp. unit.

In addition to the larger direct-connected units, there are in use a number of smaller, semi-portable, direct-connected units. These consist of a vertical tandem compressor, driven by a vertical slow-speed gas engine with an interchangeable head, so that oil may be used for fuel if desired. The capacity is about the same as the semi-portable belt-driven types.

It is the writer's belief that future developments will show a merging of the large compressors of the direct-driven type with the small semi-portable-type belt driven by electric motor or automotive-type gas engine. The small units will be installed first on account of their greater portability and will be in use while the larger units are being set. After the peak load has passed, the smaller units may be transferred to other districts, while the large permanent units will take care of the needs of the field, including any further demand for pressure or repressuring projects.

The possibilities of combining gasoline plant and gas-lift stations must be kept in mind. This plan is in use to some extent in the Seminole field at present and will doubtless be dealt with in the paper covering that field.

Discharge Manifold

In operating the first installations, no attempt was made to regulate the gas volume introduced to the wells, other than by the number of compressors used. As the compressors were set at the well, no complicated manifold was necessary: the discharge of the compressor was connected direct to the well. When the compressors were installed in a central station, it was found advisable to use a manifold of some description. Several different designs were suggested and tried, but all had the same object in view; namely, to make it possible to switch any compressor or any number of compressors on to any well connected to that particular station. This was usually accomplished by connecting the discharge line of each compressor into all the lines to the wells with suitable block gates. Individual lines were laid from each well to the compressor station. This system, while it did not permit close regulation of gas volume, was used quite extensively on account of the simplicity of operation.

It is now recognized that constant volume is of great importance in gas-lift work. An irregular supply of gas will make the wells head,

sometimes violently enough to break out the trap connections; it also has a detrimental effect on the production. Too large a volume is likely to produce excessive emulsification besides causing a large gas-oil ratio with its attending waste of energy. The use of volume controls has also made possible the use of a high-pressure loop line connected to all the wells with the volumes regulated by some type of flow controller. This effects quite a saving in line pipe. The majority of operators, however, seem to think that this saving is offset by controls being widely scattered, so the general practice is to install the volume controllers at the compressor stations.

Volume regulation is accomplished by the use of one or more of several devices: commercial flow controllers, needle valves, orifices, etc. There are several types of flow controllers on the market, all of which operate on the same general principle. The main valve is operated by a diaphragm which is connected to the upstream and downstream side of either an orifice or butterfly valve. Any change in differential across the orifice or butterfly valve will affect the diaphragm and open or close the main valve. When using these controls, common practice is to install a main header into which all the compressors discharge. The individual lines to the wells are then connected into the header and the volume controls so installed that the controller and header may be cut out and one particular compressor (in some stations, any available compressor) used to build up the high pressure usually necessary to start the well. Usually, an orifice meter is either incorporated in the controller or installed in conjunction with it. While the cost of this equipment is not excessive, it is sufficiently high to prevent its universal use and some operators have developed very satisfactory systems of volume control by the use of needle valves or orifices. The connections used are much the same. All the compressors discharge into a common header at a pressure slightly higher than the highest operating pressure of the wells. This pressure is held within a few pounds and the orifice, or needle valves in the lines to the wells, can be regulated to give the correct volume constantly. As before, a bypass is used for starting the wells.

It is important that the connections shall be sufficiently strong to withstand the high starting pressure generally encountered. The greater number of accidents can be traced to the failure of connections such as ells, tees, or gate valves and investigation has often disclosed the fact that standard connections were being subjected to several times their working pressure. The cost of connections designed for a working pressure suitable for any installation is negligible compared to loss of property and life that may be caused by the use of light connections.

Gathering System

Natural gas is used as the lifting medium in the majority of cases, outside of the Seminole area, where air is used extensively. Air is cheap

and readily available but its use has several serious drawbacks; it lowers the gravity of crude by removing lighter fractions which are not recoverable in gasoline plants, and it has a tendency to cause corrosion of tubing and casing, particularly when salt water is present. When air is used, the compressors take air from the atmosphere through a suitable screen or filter, and raise it to the required pressure to flow the wells. The mixture of air and gas produced with the oil is usually allowed to escape into the atmosphere through the release on the separator.

When gas is used, it is necessary to have a gathering system to recover it. As the majority of gas-lift compressor stations, outside of Seminole, are really booster stations, using the residue gas from the absorption-type gasoline plant, the gathering system is part of the gasoline plant. Connection is made from the trap or separator to the gasoline plant. The wet gas is brought into the gasoline plant where the gasoline is extracted. The dry gas then goes to the gas-lift compressor stations to be put back through the wells. This process is a continuous cycle and it makes possible the operation of the gas-lifts when only a small amount of gas is available in the field. The only losses are the volume shrinkage in the gasoline plant, gas used in plant operation, and a small leakage. The gas from the sand is usually sufficient to make up these losses. While the gas from the gas-lift wells will show a slightly lower content than the raw gas from the sand, there is usually more of it available, so that gasoline production as a rule does not suffer, either in daily gallonage or in profits.

In some instances where the gasoline plant is of the compression type and operating under sufficiently high pressure, the wells are flowed with gas direct from the gasoline plant.

Well Connections

The first wells produced by gas-lift at Tonkawa were Wilcox sand wells that had ceased to flow and were being produced by swabbing. These wells produced into batteries of separators centrally located so that the flow lines ranged from 100 to 600 ft. in length. A string of 2-in. upset tubing was run into each of the wells and hung on the control head by means of a common tubing hanger. The gas was introduced into the wells through the tubing and the mixture of gas and oil flowed out of the well through the annular space between the casing and tubing. The production of the majority of the wells was increased considerably and the lifting cost was less than by swabbing.

At that time no attention was paid to the length of flow lines or the elimination of right-angle bends. This has since proved to be of great importance. A good illustration of this is shown in the results obtained at Tonkawa in June, 1926, when the first changes were made.

The separator at one of the wells was moved from approximately 100 ft. from the derrick to within 10 ft. of it. The control head was removed and replaced with a welded "Y" which was connected to the

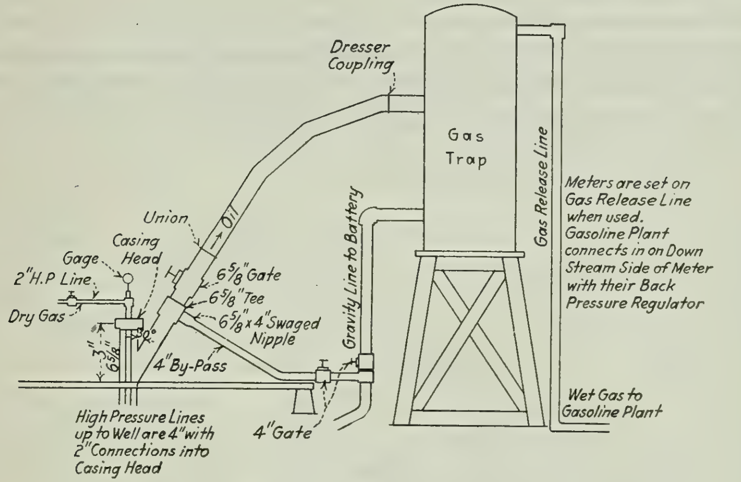


FIG. 1.—WELL CONNECTIONS FOR FLOWING THROUGH CASING.

separator in a series of gradual bends. This flow line was the same size as the well casing, so there would be no restriction in flow. Fig. 1 shows the hook-up as it appeared when completed. Immediately after these

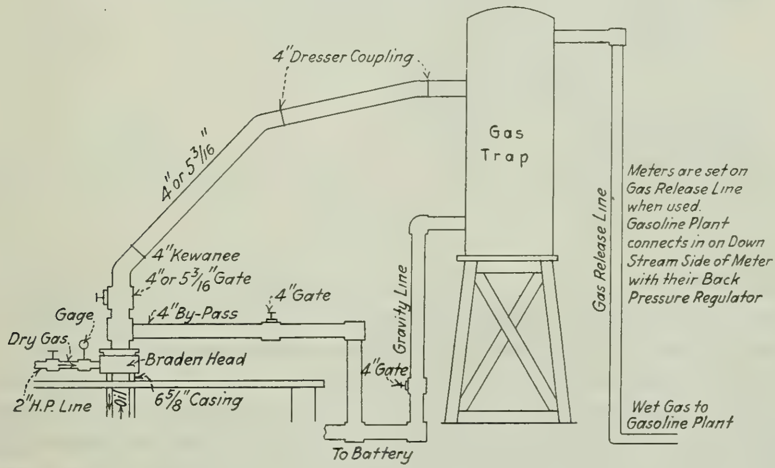


FIG. 2.—WELL CONNECTIONS FOR FLOWING THROUGH TUBING.

changes were made, the production increased 50 per cent. As there was no corresponding increase in the total gas volume from the well, a considerable decrease in the gas-oil ratio was also effected.

Fig. 2 shows the same general type of hook-up, except that it is used when flowing through the tubing. The gas is introduced into the annular space between the tubing and casing and the mixture of gas and oil flowed out through the tubing.

A combination hook-up for flowing through either the casing or tubing is shown in Fig. 3. The starting pressures, outside of the Seminole area, are not high enough to require the general use of this type of connection. In cases where high starting pressures are encountered and it is

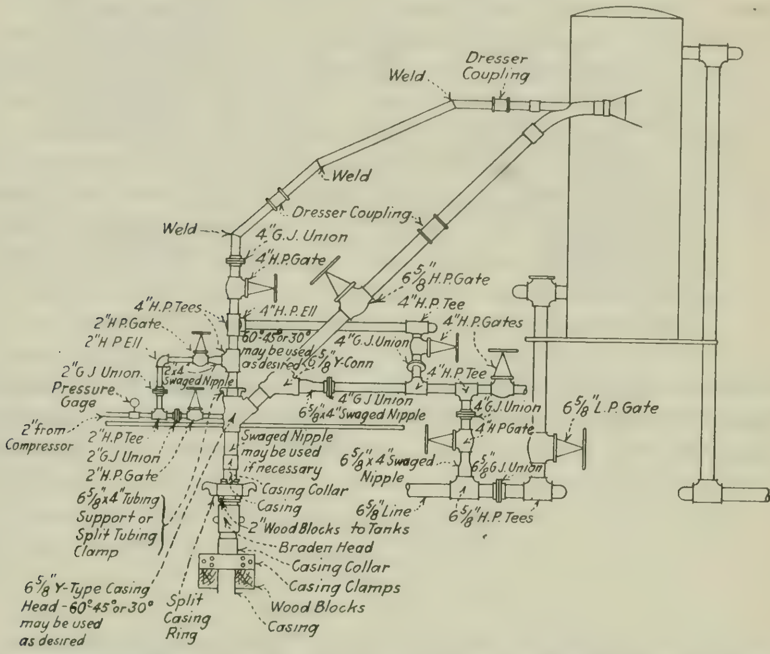


FIG. 3.—COMBINATION CONNECTION FOR FLOWING THROUGH EITHER CASING OR TUBING.

desirable to reduce this excessive pressure, the well is connected up as shown in Fig. 3 and is rocked. That is, the pressure is alternately built up and released, first in the casing, then in the tubing, or vice versa, until the oil is livened up sufficiently to reduce materially the starting pressure.

These sketches do not show the position of the orifice meter, which is placed on the gas-release line between the trap and the gas-gathering line connection, in order to measure all the gas from the well. Gas measurements of the gas introduced to the well and of the total gas coming from the well are worth many times the money spent for equipment to secure the information. No idea of the efficiency of the lift can be obtained without this information.

DISCUSSION

E. H. Griswold,* Ponca City, Okla.—The trend of air-gas lift development in Oklahoma shows a decided tendency toward centrally located compressor plants and also toward combination gasoline-gas lift plants on properties of sufficient size to make gasoline recovery advisable. Leases which under former producing methods could not support a gasoline plant can be profitably equipped with one, taking advantage of the lower installation cost when used as an accessory to a gas-lift plant and of the increased recovery of natural gasoline due to recycling.

Automatic volume controls have proved of great value, repaying their cost within a short time by means of a more efficient utilization of compressor capacity and increased oil production. They are almost a necessity if the gas factors are to be controlled with any degree of accuracy.

As Mr. Bond says, the elimination of sharp bends in the flow lines has led to better results. Probably the slight back-pressure caused by these sharp bends has no noticeable effect, but the temporary reduction in velocity at the bends causes excessive slippage and loss of production. Too large a flow line gives results similar to a sharply angled one. It is advisable to avoid horizontal or upward sloping flow lines, as stratification of the oil and gas occurs and reduces the lifting power of the gas unless the velocities are relatively high.

Flow beans on the outlets of gas-lift wells have been successfully used to steady the flow and reduce the inlet, outlet and natural gas factors. Back-pressures up to 50 lb. per sq. in. were applied with correspondingly little effect on the required working pressures. A back-pressure of 105 lb. was used on one well before the daily oil production was materially decreased. Another gas-lift well has been operated with a 50-lb. back-pressure for several months with most satisfactory results.

---

* Marland Oil Co.

Mechanical Installations for Gas-air Lifts in the Seminole Area*

By Clifton R. Swarts,† Bartlesville, Okla.

(Fort Worth Meeting, October, 1927)

The use of compressed air or gas in oil wells for raising crude oil to the surface has, within the last year, become a dominant factor in production engineering. Previous application of this principle was largely confined to oil wells that had been pumping for a considerable length of time. In the Seminole area, the gas-air lift has been applied to wells immediately after natural flow has ceased and in some cases while the wells were still flowing. This early application of the gas-air lift has been watched with intense interest by the petroleum industry, both with respect to methods of application and mechanical installations and to the effects on immediate and ultimate production.

Methods of Application

The Seminole pool at its inception contained sufficient gas associated with the oil to cause natural flow. As no free gas was found in the main productive horizon, the Wilcox sand, all the gas present was dissolved in the oil, hence the natural flowing life was short, rarely lasting over 45 days. When natural flow ceased, high fluid levels were common, and as depth and crookedness of holes were obstacles to efficient pumping, the gas-air lift was used almost exclusively in raising the oil to the surface.

Because of the high gravity of the oil, 41° A. P. I., and its high gasoline content, and also because of the desire to obtain production before offset wells became productive, quantity of production was the aim of the operators and a method of flow was used whereby this aim could be fulfilled. One of the outstanding features of this method consisted in flowing the wells through the annular space between the tubing and casing. By this means a greater quantity of fluid could be handled than by flowing through the tubing of the size in ordinary use. Wells that would produce only a few hundred barrels on the pump were by this method made to produce as high as 7000 bbl. on the lift. A few days or weeks of production at that rate meant a large recovery of oil.

Casing of $6\frac{5}{8}$ in. diameter was commonly used as a production string with a $5\frac{3}{16}$-in. liner set on top of the oil sand. Upset tubing for intro-

---

* Presented by permission of the Director, U. S. Bureau of Mines.

† Petroleum Engineer, U. S. Bureau of Mines.

ducing the gas and air 2 and $2\frac{1}{2}$ in. The tubing was lowered within a few hundred feet of the top of the oil sand and sufficient air or gas was introduced at the required pressure to cause the well to flow. In a few cases fluid levels were measured and the desired depth for the tubing was calculated from these measurements. Tubing depths were frequently changed to increase daily production.

When production had declined so that the annular cross-sectional area between the tubing and casing was more than sufficient to accommodate the quantity of production, the flow was reversed[1] in order to reduce the amount of air or gas below that required when flowing through the casing. Some of these changes were successful in that they maintained or nearly maintained the previous rate of production and at the same time reduced the compressor requirements. More often, however, the results were unfavorable from the viewpoint of the operator, as the decrease in production more than offset the advantage gained by the reduction of the air or gas requirements. One or two companies used tapered tubing ranging from 2 in. at the bottom to $5\frac{3}{16}$ in. at the top. In most cases the use of tapered tubing was successful, resulting in lower working pressures, reducing the quantity of gas used and maintaining about the same rate of production. In one well production was increased about 50 per cent.

Flowing Pressures

Pressures usually necessary to start flow varied from 250 to 750 lb. depending principally on the depth of tubing in the fluid column and the gravity of the oil, resistance due to friction being negligible. Pressures higher than 750 lb. have been recorded and on one well a pressure of 1400 lb. failed to start flow. No attempt was made to reduce starting pressures by "rocking pressures" or "super-flushing," as practiced in the Texas Panhandle.[2]

Flowing or working pressures varied from 50 to 700 lb., depending on the method of flow. In the use of tapered tubing pressures as low as 50 lb. were recorded and with flow through tubing of uniform diameter pressures were as high as 700 lb. The majority of wells were flowed through the casing, however, and the average working pressure on these wells was about 190 pounds.

Gas and Air Required

The quantity of gas or air required per well per day varied greatly, ranging from 400,000 cu. ft. to 1,200,000 cu. ft., the average being from

---

[1] Reversed is used in the sense of changing the oil from flowing through the casing to flowing through the tubing, or vice versa.

[2] E. O. Bennett and K. C. Sclater: Volume and Pressure Control for Wells on Gas-lift.

750,000 to 800,000 cu. ft. In the field, 800,000 cu. ft. is used in designing pressure plants. When production had declined to such an extent that the cross-sectional area between the tubing and casing was more than sufficient to accommodate the decreased quantity of production, operators continued to flow through the casing notwithstanding the fact that this method required excessive amounts of gas. This can be explained by the fact that most operators wished to maintain the established rate of production. When flow was changed either to tapered tubing or tubing of uniform cross-sectional area, a smaller quantity of gas was required but with a decreased rate of production, even though better efficiencies with respect to gas-oil ratios were obtained. The lowering of fluid levels also accounted for relatively more gas being required to lift the oil.

Well Connections and Flow Lines

Connections at the well head were of simple design when flowing through the casing. A suitable tubing packer and support of sufficient

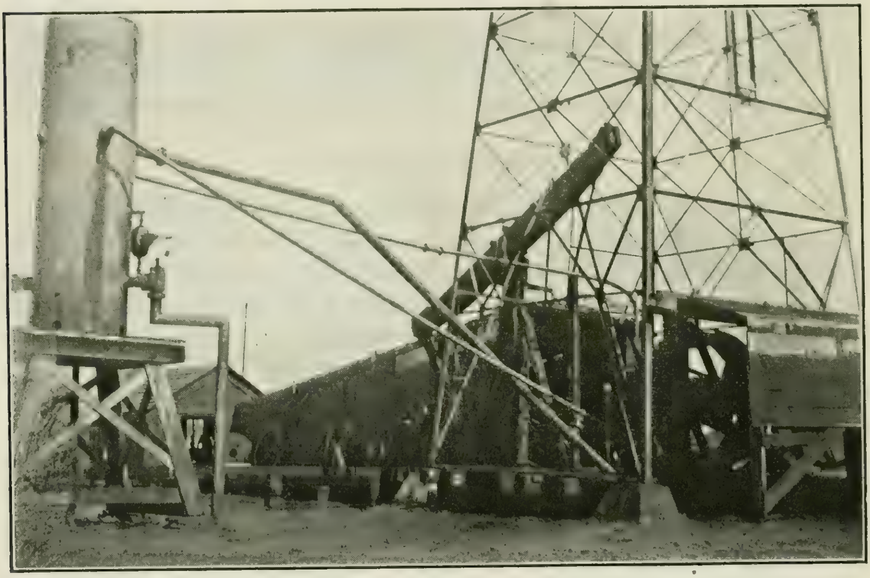


Fig. 1.—Well and top connections for flow through tubing or casing.

strength to withstand starting pressures was screwed into the control head or directly on to the casing. Several companies designed their own tubing packer. A pressure gage at the well head recorded the working pressure.

Oil flow lines were 4 and 6 in. directly connected to the control head or to the casing below the well-head connections. One design of special interest had the flow line welded to the casing below the derrick floor and at such an angle that the flow line led directly to the trap where with a slight bend it connected with the trap (Figs. 1 and 2). The general

practice was to eliminate all right-angle bends between the well head and the trap, to lessen resistance to flow.

Traps were placed on elevated platforms adjacent to the derrick and high enough to permit the oil to flow by gravity to the stock tanks. Traps varied in size from 4 by 12 ft. to 8 by 20 ft. Common commercial traps and separators were used.

The first installations of flow connections at wells did not allow for reversal of flow, therefore in order to change the method of flow the connections at the well head had to be changed. Fig. 2 shows well connections for reversal of flow. In the use of tapered tubing a head of a different type was used to accommodate the larger size tubing at the well head. By regulation of the necessary valves, flow could be directed through tubing or casing.

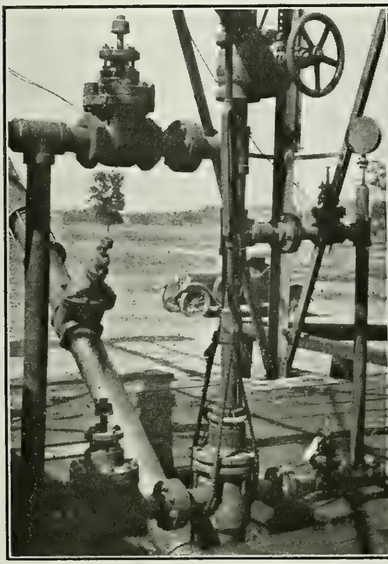


FIG. 2.—TOP CONNECTIONS FOR REVERSAL OF FLOW.

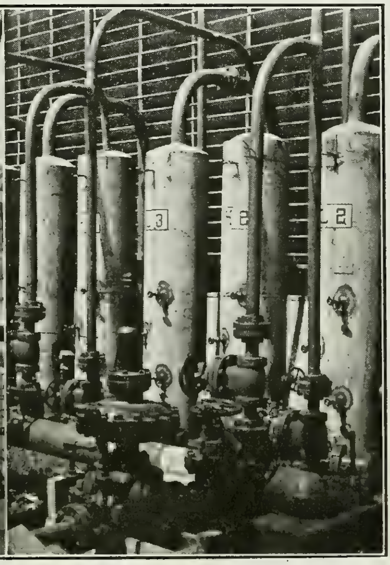


FIG. 3.—PART OF A PLANT WITH HEADER SYSTEM.

COMPRESSOR PLANTS

Starting pressures, working pressures, and cubic feet of gas or air used per well per day were important factors in selecting compressor equipment. The plants ranged in size from the small portable plants of three compressors to the larger semi-permanent and permanent plants having as many as 30 compressors. The size of compressors ranged from $9\frac{1}{2}$ by 4 by 10 in. in the smaller plant to 16 by 8 by 20 in. in the larger plants. The number of wells to be flowed and the amount of gas required per well per day determined the number and size of compressors. Very few tests were made on wells to determine the amount of air or gas required per

day and installations were usually made according to the average input per well per day as determined by previous operations. Three to four small compressors $9\frac{1}{2}$ by 4 by 10 in.; two 80-hp. compressors, $9\frac{3}{4}$ by 5 by 20 in., or one 160-hp., 15 by $7\frac{1}{4}$ by 20 in., were used per well. The size of cylinders could be changed on the larger compressors, allowing for changes in plant capacity. The above sizes were capable of delivering 800,000 cu. ft. of gas or air per day at working pressures up to 500 lb. and starting pressures up to 1000 lb. Compression was always two stage.

The smaller compressors were belt driven by electric motors of 75 or 100 hp. and the larger sizes were direct driven by gas engines.

Distribution System

Two general plans of air and gas distribution were used, one employing the header system in conjunction with a central plant supplying a large number of wells. The other system consisted of a battery of compressors directly connected to an individual well. The header system was more commonly used. Many variations in the header system were evident but all accomplished about the same results. The manufacture of gasoline in connection with lift work resulted in special design of plants. The majority of plants provided for a working header and a high-pressure header for starting wells. Starting headers were divided into as many as four sections, which could be used simultaneously, thus allowing four wells to be started at once. Several plants contained intermediate headers between high and low compression which with fuel and water headers made as high as seven headers per plant.

Fig. 3 shows a portion of a plant using the header system. The flow of gas in this plant is as follows: the gas enters the system through two scrubber tanks, thence to a $15\frac{1}{2}$-in. intake header to the low-compression cylinders, compressed to 50 or 55 lb. and discharged into a 10-in. low-pressure discharge header. From the low-pressure discharge header the gas passed through condensing coils to a low-pressure gasoline accumulator 18 in. by 7 ft. Gasoline was removed by an automatic gasoline trap. From the low-pressure accumulator the gases passed to a 12-in. high intake header and thence to the high-compression cylinders where it was compressed to about 250 lb., passing directly through the cooling towers to the high-pressure gasoline accumulators. From these accumulators, the gas passed to a working header and was distributed to individual wells through volume-control devices and orifice meters. From the high-pressure gasoline accumulators the gas could be directed to a high-pressure starting header capable of handling four wells at one time.

Compressor equipment in the type of plant described consisted of five 165-hp. Bessemer compressors, having 15 by $7\frac{1}{4}$ by 20-in. cylinders and eight 80-hp. Bessemer compressors, having $9\frac{3}{4}$ by 5 by 20-in. cylinders.

The water circulation in plants was either forced feed or gravity flow. Some plants used individual cooling towers for jacket water and others used water from the condensing tower. The systems were so connected that water could be used from either source.

Where headers were not used (Fig. 4), the distribution of gas through the plants was very similar. The gas passed through scrubber tanks to a 20-in. low intake header, thence to the low-compression cylinders and was compressed to 50 or 55 lb. After low compression, the gas passed directly through the condensing towers to the low-pressure gasoline accumulator, thence to the high-compression cylinders and after

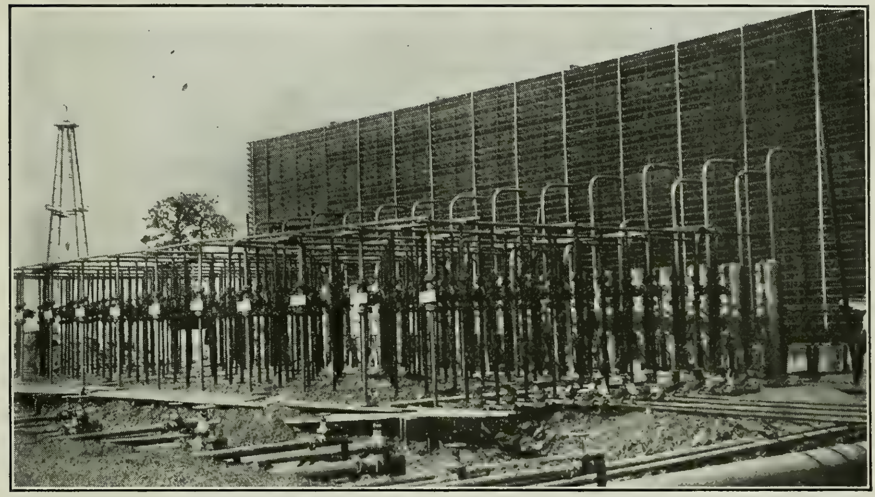


Fig. 4.—Compressor-plant manifold; unit of compressors directly connected to well.

compression passed to the high-pressure gasoline accumulators, thence to a regular pipe-line manifold. This permitted the distribution of gas from any compressor to any well. No volume-control devices were used on this type of plant, the volume being regulated by pinching the intake valves on the compressor or pinching the valve controlling the flow to wells. Orifice meters at the plant or well measured the flow of gas. Water circulation was either forced feed or gravity flow and was so connected as to permit flow from the cooling tower or from the condensing tower as in the plant using the header system.

Variations were evident in both types of plants. In many plants there was no cooling of gas or extraction of gasoline after high compression, the gas going directly to the wells. Nearly every plant allowed for the extraction of some gasoline between low and high compression.

The coolers used to extract gasoline were either the shell type placed vertically or horizontally or coils sprayed by water.

In each of the two general types of distribution there are advantages and disadvantages relating to the use of gas and air and the utilization of power. Under the header system, compressor capacity can be fully utilized, as only the number of compressors necessary to flow the wells need be used. The breakdown of a compressor does not shut down a well, as other compressors can take on the load of the broken compressor. Pressure carried on the header must necessarily be greater than the largest pressure required to flow a well. Any defect in the header would cause the shutdown of the entire plant. The change from air to gas cannot be made without shutting down the entire plant.

Under the system in which the wells are directly connected to a battery of compressors, change from air to gas can be made one well at a time, without shutting down the entire plant. Shutting down a battery of compressors means the shutting down of a well. The maximum capacity of a battery of compressors is not fully utilized when low working pressures are required.

Installation Costs

Development in the Seminole area was so rapid that only approximate costs were available. Roughly, the small units consisting of three 9½ by 4 by 10-in. compressors cost \$4500 to \$5000 each or \$13,500 to \$15,000 per well. Units of 80 hp., consisting of two 9¾ by 5 by 20-in. compressors, cost from \$10,000 to \$12,000 each or \$20,000 to \$24,000 per well. Units of 165 hp., consisting of one 15 by 7½ by 20-in. compressor, cost \$17,000 to \$20,000 per well. These costs include everything in connection with installation of the plant up to the operating point.

Operation costs varied as to the manner in which they were computed. On a basis of cubic feet of gas handled, costs were about 9 cents per 1000 cu. ft.

Summary

The Seminole field has had the most intensive application of the air-gas lift of any field in the United States. The practice has been to follow general principles of application with elaborations along certain lines. In plant construction, right-angle bends have been eliminated as far as possible, by using 45° bends or by bending the pipes in a special machine. Each plant is different in detail, the difference in construction being due to the engineer in charge.

Companies are building several kinds of plants, experimenting with each with respect to construction, equipment and operation with the idea of standardization in mind. When that point is reached, costs of construction and operation will be greatly reduced.

[This paper was discussed in the General Discussion. See page 112.]

Mechanical Installations for Gas-lift Pumping as Practiced in the California Oil Fields*

By H. C. Miller,† San Francisco, Calif.

(Fort Worth Meeting, October, 1927)

The gas-lift method of flowing oil from wells is the outstanding feature of petroleum technology today. Its forerunner, the air-lift, was used successfully first, in the Baku fields of Russia, in 1899, and later in the Gulf Coast fields of Texas and Louisiana and the Kern River field of California. It is still used to a limited extent in certain oil fields. The use of compressed natural gas for lifting oil from wells has supplanted the air-lift method in a measure in those fields where a sufficient quantity of gas accompanies the oil to make the gas-lift possible, or where natural gas is plentiful and inexpensive. We find, therefore, in California, that natural gas is used at practically every well where a gaseous medium is employed to flow the oil.

The use of natural gas has many advantages over that of air. It is possible to recover and save the gasoline from the gas that accompanies the oil to the surface. This gasoline would be wasted if air were used as the lifting medium. Also, certain proportions of air and gas form an explosive mixture that cannot be handled safely by compressors. Another advantage that gas has over air is that gas under pressure is more soluble in oil. Gas in solution in oil reduces the viscosity of the oil that is being produced and causes it to flow more readily through the tubing and flow lines.

The gas-lift has made it possible to recover many thousands of barrels of oil from deep wells in California that could not have been produced otherwise. It would not have been economical, had it been mechanically possible, to produce such wells as the world's deepest producing oil well (Miley Athen's No. 6, Rosecrans field, California) by any other method of pumping known today. At this well, production is obtained from between 7305 and 7591 ft. and 11 months after completion of the well, production was being maintained on the gas-lift at approximately 2000 bbl. a month.

The crookedness of the hole, or its diameter and depth will not prevent the successful application of gas-lift pumping when other conditions are favorable.

---

* Published by permission of the Director, U. S. Bureau of Mines.

† Petroleum engineer, U. S. Bureau of Mines.

During the past 2 or 3 years, the oil industry has been awakened to what can be accomplished by the gas-lift and though this method has been extensively applied in California and elsewhere, it is far from being a cure-all for all pumping difficulties. Much study and experimenting are necessary before all the mechanical details of the gas-lift will be fully understood. Many developments unthought of today will widen the application of the gas-lift method of pumping oil from wells.

Principles of the Process

Oil wells equipped for the gas-lift method of pumping are customarily tubed in such a manner that the flow of oil to the surface is either through the tubing or through the annular space between the tubing and the well casing. The usual procedure in California is to introduce the compressed gas into the casing at the casinghead. The oil from the well, accompanied by gas from solution in the oil, and free gas from the formation, including extraneous gas pumped in, flows to the surface through the tubing. This mixture of oil and gas from the well flows directly into a gas trap where the gas is separated from the oil. The gas from the trap is conveyed in the intake line to a gasoline plant where, by a series of compressions, and cooling, the gasoline is recovered. In large installations, the wet gas from the wells after being compressed from approximately atmospheric pressure to 25 or 30 lb. per sq. in., is passed through an absorption plant and then further compressed to 250 or more pounds pressure depending upon the required working pressure at the well.

The above is a very general outline of the principles of the process of pumping oil from wells by the gas-lift method. Many variations of this method are in evidence throughout the oil fields of California. Sometimes portable compressors are used that take the wet gas directly from the gas traps, compress it and recirculate it down the well. The excess gas from such systems is delivered through pop valves into the lease compressor and absorption plant intake lines. Still another method is to treat the gas from the well in a low-pressure absorption plant, then compress it to the required working pressure and circulate it down the well. This method is inefficient because a relatively high back-pressure, 25 or more pounds, must be maintained in the gas traps in order to force the gas through the absorbers.

Operating Gas Pressures

Normal working gas pressures vary with the pressure in the oil-producing formation, the gravity (density), viscosity and surface tension of the oil, the back-pressure held at the tubing head, and the volume of gas per unit volume of oil lifted. Some foot pieces also have a marked

effect on the operating gas pressure. A slight change in any one of these variables is reflected in the pressure necessary to operate the gas-lift. It is therefore not surprising to find adjacent wells operating on widely different gas pressures. Operating pressures varying from 100 to more than 350 lb. per sq. in. have been noted in one small area where the wells were about the same depth and producing the nearly equal quantities of oil from the same sand. Normal working pressures of 125 to 275 lb. per sq. in. for lifts of 4000 ft. are common in California. In exceptional cases however, operating pressures up to 650 lb. per sq. in. have been noted.

Starting Pressures

Starting pressures are usually from 2 to 5 times higher than normal operating pressures. High starting pressures are due to the greater density of the column of unaerated fluid in the well. This fluid offers greater resistance to flow than the mixed column of gas and oil flowing through the eduction tube during normal operation of the gas-lift. Because of the high starting pressures often required, compressors capable of furnishing gas at pressures higher than that required for normal operation are usually installed at gas-lift wells. When gas is being supplied to a number of wells from a central compressor plant, a booster compressor capable of furnishing gas at pressures of 1000 or more pounds per square inch is installed.

In order to reduce the required starting pressure as much as possible, so as to avoid excessive high pressures which might injure many wells by forcing the oil back into the formation, provision is made at the casing-head at many wells to reverse the flow of gas down the well. The gas intake line to the well is so arranged that by manipulating certain valves in the gas line, the gas is caused to flow first down the tubing and then down the annular space between the tubing and the casing. Often two or more reversals of direction of the gas flow are necessary to start a well. This method of starting the flow of oil is known as "rocking." The oil can be forced out of the tubing and aerated at a lower pressure than would be required were the direction of flow of gas down the annular space between the tubing and the casing and the attempt made to aerate the oil in the tubing, or to blow it out without first lightening it with gas. This is true because of the difference in cross-sectional area of the tubing and the space between the tubing and the casing.

For example, let us suppose that the fluid level in a well stands 500 ft. above the bottom of a string of 2½-in. tubing suspended inside of 6¼-in. casing. The total volume of oil within the tubing is 16 cu. ft. The volume of oil outside the tubing is 69 cu. ft. When sufficient pressure is applied at the tubing head to force all the oil out of the tubing, the fluid level outside the tubing is raised 116 ft. and the pressure necessary to

empty the tubing of oil is 243 lb. per sq. in. if frictional losses are neglected and oil free of gas pockets and of 24 A. P. I. gravity is assumed. On the other hand, if the source of gas pressure is at the casinghead, the oil in the tubing will rise 2123 ft. and again neglecting friction losses, the pressure required to force all the oil into the tubing will be 1036 lb. per sq. in. It is evident from the above that lower starting pressures are necessary when a well is "rocked" at the start or after a period of idleness.

Gas Volume Required

The volume of extraneous gas required to flow a well by the gas-lift method depends upon the rate at which the oil is raised, the size of the eduction tube, the volume of formation gas per unit volume of fluid raised, the position of the eduction tube with respect to the oil zone, and in some cases upon the type of flow device used in the well.

Many wells in California are made to produce oil at a total extraneous gas consumption of only 350 cu. ft. per bbl. of oil. The average however of a large number of wells operating under widely diversified conditions and producing oil from depths of 3800 to 4500 ft. is somewhere between 1200 and 1500 cu. ft. of gas pumped in to the barrel of gas produced.

Equipment

Sufficient volume of gas at pressures up to 300 or more pounds per square inch is required for pumping oil wells by the gas-lift method. This gas may be obtained from high-pressure gas wells, as is done in several places in California, or taken from a low-pressure source of supply and its pressure raised by means of compressors. No two compressor installations operate under the same conditions because gas volume and pressure requirements differ for each well. Wells that respond to the gas-lift method of pumping generally require the maximum volume of gas when first placed on the gas-lift or soon thereafter. The working pressures also are usually greatest at the time the well is placed on the gas-lift. Moreover, the starting pressures required are often two or more times the working pressures so that individual compressor installations must be designed to meet the maximum gas volume and pressure requirements. For this reason, many compressors now in operation have a much greater capacity than is necessary for efficient operation. Unless the cylinders are frequently changed so as to more nearly satisfy the changed pressure and volume requirements, or the speed at which the compressors are operated is altered, there will necessarily be a waste in operation. Because of this inefficient operation of individual units, large central compressor plants are used for gas-lift purposes wherever possible.

Compressor Installations

1. *Portable and Semi-permanent Installations.*—Many operators use one or more gas-engine, electric-motor, or steam-driven compressor units for bringing in, testing, and pumping individual wells. These units are usually mounted on four-wheel trucks or on skids and can be readily and easily moved from well to well. Such portable equipment is generally for temporary use only. It is moved to another well as soon as a permanent installation is completed, or the well has been tied into the gas line from a central compressor plant. The compressors of portable units are usually either duplex, or straight-line tandem, two-stage machines. Low-pressure gas cylinder diameters range from 8 to 12 in. High-pressure cylinder diameters range from 4 to 6 in. and the length of strokes from 8 to 12 in. The majority of portable and semi-permanent units in California use 8 by 4 by 8 in. compressors running at a speed of about 250 r. p. m. The size of gas engines and motors for portable units vary according to the power requirements of the compressors. Gas engines rated at 40 to 60 hp. and electric motors up to 100 hp. are generally used on portable compressor units. A few semipermanent units are steam-driven, straight-line machines with 9-in. low-pressure and 4-in. high-pressure gas cylinders, 12-in. steam cylinders and 10-in. stroke.

2. *Permanent Installations.*—Few large compressor plants have been built in California primarily for furnishing compressed gas for flowing oil wells. On most properties, compressor plants had been built before the advent of the gas-lift, to recover gasoline from the casinghead gas and to compress the gas to pressures high enough to buck the line pressures in the commercial gas companies' gas collection systems. This pressure varies usually from 250 to 325 lb. per sq. in. These companies furnish gas for domestic and industrial purposes to cities in the Los Angeles Basin, San Joaquin Valley cities and towns and to consumers in Santa Barbara and Ventura counties.

The problem of furnishing gas to flow wells by the gas-lift method on properties where a compressor plant is in operation is therefore a simple matter. The addition of a gas-distributing header with individual lines to the wells, or a gas-distributing system consisting of main lines about the property with individual lines to the wells, the installation of a booster compressor where high starting pressures are necessary, and the installation of gas volume-control apparatus at each well where the manually operated central header system is not to be used, constitute the only added facilities required.

The Richfield steam-driven compressor plant of the Union Oil Co. of California consists of 19 Chicago Pneumatic single-stage, direct-connected, steam-driven compressors. Thirteen of these units are 10 by

10 by 10 in., five are 10 by 7 by 10 in. and one is a 10 by 6 by 10 in. compressor for starting or booster purposes; also used in conjunction with the five 7-in. machines when starting pressures are not required. Each compressor is driven by one 80-hp. Broderick, return tubular boiler.

The wet gas from the wells at 10-in. vacuum is first compressed in a separate compressor plant to 30 lb. per sq. in. and circulated through an absorption plant where its gasoline is recovered. The intake gas to the thirteen 10 by 10 by 10-in. units in the steam-driven plant is taken from the absorption plant discharge line at 20 lb. and compressed to 140 lb. per sq. in. The 7-in. and 6-in. compressors then take this gas at 130 lb. pressure and further compress it to a pressure of 325 lb. per sq. in. This plant delivers 8,000,000 cu. ft. of gas per day at 325 lb. pressure to an 8-in. distributing header equipped with Wescott recording meters and gate valves for controlling the volume of gas to each well. These meters are located at the header on the 3-in. individual lines to the wells. The booster compressor is connected to the distributing header in such a manner that high-pressure gas may be delivered to any one of the 19 or more wells.

The gathering system that brings the wet gas from the gas separators at the wells to the low-pressure compressor and absorption plant consists of main lines 16 in. in diameter with 4-in. and 6-in. dia. individual lines from the well traps.

The new Richfield gas-driven compressor plant of the Union Oil Co. of California consists of four 320-hp. and one 640-hp. Worthington direct-connected compressors. The 320-hp. machines have 16-in. intermediate and 9½-in. high-pressure cylinders; the 640-hp. compressor has a 22-in. intermediate and a 13-in. high-pressure cylinder. The length of stroke on all machines is 20 in. The diameter of the gas engine cylinders is 18½ in. The 320-hp. compressors are each equipped with two, and the 640-hp. machine with four of these 18½ by 20-in. gas cylinders, each of which is four-cycle, double-acting.

As at the Richfield steam plant, the intake gas to the gas-driven plant is taken from the absorption plant discharge at a pressure of 20 lb. per sq. in. The discharge from the intermediate cylinders enters the high-pressure cylinders at 80 lb. and is discharged at a pressure of 325 lb. per sq. in. The capacity of this plant is 12,000,000 cu. ft. of gas per day at 325 lb. pressure.

A compressor plant installation for flowing four wells at Cat Canyon, Santa Barbara County, California, consists of two Ingersoll-Rand two-stage compressors with 12 by 12-in. low-pressure and 6 by 12-in. high-pressure cylinders. The compressors are driven by 110-hp. Bessemer gas engines, size 13½ by 18 in. The intake gas enters the low-pressure cylinders at atmospheric to 3 lb. per sq. in. pressure and compressed to approximately 100 lb. From the low-pressure cylinders the gas passes

through a cooling tower where a small amount of gasoline is recovered. The gas is then compressed to about 500 lb. per sq. in. in the 6 by 12 in. cylinders and delivered to the main distributing line. The individual lines to the wells take off from this distributing line. As each well operates under slightly different volume and pressure, volume regulating control valves are installed on each of the individual lines to the wells. After the gas passes through the control valves it is preheated to about 200° F. before it enters the well casing.

Intermittent Flowing Systems

The intermittent or impulse system of flowing a number of wells from a single compressor plant of limited capacity is practiced to some extent in California. This method requires less compressor capacity than is necessary were each well flowing simultaneously. Six wells on a property in the Torrance field are being successfully flowed by the intermittent system. Three steam-driven compressors, under governor control, handling gas up to 350 lb. per sq. in. pressure, furnish enough gas to operate these six wells which produce around 500 bbl. of 19 A. P. I. gravity oil daily.

In the intermittent system, all the gas from the compressors is automatically turned into one well at a time and allowed to discharge into that well for a predetermined length of time. In this way[1] the compressors build up sufficient pressure to flow the well, and after flowing, the gas under pressure passes on to the next well to secure like results. For this reason the compressor speed is regulated by governors. Distribution of gas from one well to another is accomplished by a clocklike contrivance which revolves as a dial, pins being placed at intervals which cause electric contact, which in turn effects the opening of small valves releasing pressure to actuate a trip placed at the manifold on the gas discharge line. As soon as the time limit for a certain well is reached the trip automatically causes a cam shaft to revolve a portion of a turn and in doing so the projecting cams open a second valve by depressing the valve stem. This automatic time regulation changes the direction of the total flow of the gas from one well to another, at previously determined time intervals. In this manner, each well receives the full discharge of the compressors for approximately 3-min. periods, or each well of the six receives the full volume of gas about once every 18 or 19 minutes.

Volume and Flow Control of Gas to Wells

The proper control of the volume and pressure of the gas to individual wells on the gas-lift is essential. For highest efficiency, these factors

[1] Ben C. Dumm: How California Operators Are Applying the Gas Lift Principle on Flowing Oil Wells. *Petroleum World* (April, 1927) 82.

should be maintained reasonably constant. At some wells, hand control has proved satisfactory and many operators in California are resorting to this method of maintaining proper pressure and volume of gas to the wells. At many large-scale installations of gas-lift flowing methods where the gas to the wells is distributed from a common header, the volume of gas to the individual wells is regulated manually at the header by opening and closing gate valves installed on the individual lines at the header.

Some operators on the other hand prefer and use automatic control devices because they believe that mechanical pressure and volume-control devices are more reliable and effective and that by their use more oil is produced at a lower cost per barrel. Several types of automatic gas-volume regulating devices are in use in the California oil fields. Two types will be described in this paper, the Foxboro and the Natural Gas Equipment Co.'s controllers.

The Foxboro gas-volume and flow controller consists of an orifice meter with mercury float-type differential recording gage and a volume-control unit. The orifice meter operates on the well-known principle that when an orifice of smaller diameter than the line itself is placed in a pipe line carrying a liquid or gas, a drop in pressure is created between the upstream and downstream base of the orifice plate. This drop in pressure, which is known as the differential pressure, is recorded on a 24-hr. clock-driven chart. The flow of gas or liquid through the pipe line may be computed from the recorded data on this chart. The volume-control valve on lines carrying gas is gas-operated through control mechanisms in the recording instrument. The rate of gas flow to the well can be automatically controlled and the pressure on the well kept uniform and the volume constant, by setting the index arm on the face of the differential gage to a differential pressure corresponding to the flow of gas desired. If the flow tends to increase beyond the desired point, the control mechanism tends to shut down the flow, and vice versa.

The Natural Gas Equipment Co.'s differential regulators are also used in connection with wells flowing by the gas-lift. This equipment, like the Foxboro, is used to maintain a constant flow of gas to the well. When a well heads and the pressure in the well goes up due to oil accumulating in the well above the inlet of the tubing, the device automatically increases the volume of gas to the well and reduces the heading cycles. Under opposite conditions, as when too much gas is being delivered to the well and the pressure is reduced, the volume of gas flowing through the line is automatically decreased. The rate of flow of gas to the well is accomplished by maintaining a predetermined difference in pressure between the upstream and downstream sides of an orifice installed in the gas line. The differential regulator is installed in the same line, either above or below the orifice plate. The high-pressure side of the diaphragm which actuates the valve in the regulator, acts against the lesser gas pressure

on the downstream side of the orifice and against the tension of a spiral spring. This spring may be set for the desired difference in pressure of the gas. Changes in gas flow may be made by changing either the size of the orifice, or the adjustment of the spring tension. Any type of differential pressure recorder may be installed with this gas flow regulator when it is desired to record the differential pressure on a chart in order to compute the volume of gas flowing through the line to the well.

Gas Preheaters

Preheating the compressed gas by steam before it enters a gas-lift well, in an ordinary type of heat interchanger, has made it possible to flow some of the low-gravity California oils. In Cat Canyon, Santa Barbara County, 11.5 A. P. I. gravity oil, so viscous that it will not flow at ordinary temperatures, is being flowed successfully from a depth of about 2900 ft. by the use of heated gas. The compressed gas at 475 lb. per sq. in. pressure is heated by steam to about 200° F. in a preheater made out of a piece of 10-in. casing 4 ft. long. The gas passes through 38 tubes, 3 ft. long, which are welded in headers and enclosed in the preheater, and is delivered to the well where the temperature at the casinghead is maintained at 190° F. The oil from the well has a temperature of 100° F. at the casinghead.

Surprisingly small volumes of heated gas are required to flow this oil, the viscosity of which has been appreciably lowered by the heated gas. Two wells, producing respectively 275 and 350 bbl. of oil daily are being flowed by 330,000 cu. ft. of heated gas a day at 500 lb. per sq. in. pressure. This volume of gas is being furnished by one compressor.

Some low-gravity oils, in California, have also been successfully flowed by preheated air. One well in particular, when flowing through 3-in. casing from a depth of 2000 ft., flowed 250 bbl. of 16 A. P. I. gravity oil a day with 340,000 cu. ft. of air at a temperature of 190° F. When the temperature of the air was raised to 300° F. and the tubing diameter increased to 4 in., production rose to 325 bbl. at an added consumption of only 60,000 cu. ft. of air per day. The normal working air pressure in both cases was 240 pounds.

Many gas preheaters are "home made" affairs. Those that have come to the writer's attention, in addition to the one described above, were made of used 11⅝-in. casing about 20 ft. long. A coil of 2-in. pipe, bent so that the gas or air passing through it made three complete passes from end to end of the casing shell was inserted inside the casing. The ends of the coil passed through metal heads welded at the ends of the casing. The air or gas therefore traveled a distance of nearly 60 ft. inside the heater. The steam which surrounds the 2-in. coil enters the casing near one end through a 1-in. nipple and exhausts through a similar size nipple at the opposite end.

Few California wells give trouble because of the paraffin content of the oils. Where paraffin has deposited in the eduction tubes in a few wells operated on the gas-lift and has reduced production by decreasing the effective inside diameter of the tubing, preheating the gas has been beneficial in preventing the deposition of paraffin. Heating the gas slightly by injecting live steam directly into the gas line to the well for short periods at weekly intervals is another method that has successfully eliminated paraffin troubles at some wells, especially those in the Santa Fe Springs oil field.

Gas Traps

In order to separate the gas from the oil and to recover the gas, it is necessary to flow the mixture of oil and gas from the well into gas traps or separators. Vertical cylindrical traps capable of withstanding pressures ranging from partial vacuum to 50 or more pounds per square inch and actuated by internal floats or external mechanical contrivances are used for this purpose in California. The majority of gas traps are located at an elevation above the derrick floor so that the oil will flow by gravity to the gage tanks and thus reduce the back-pressure on the well to a minimum. Sometimes the traps are located in the derrick 20 to 30 ft. above the derrick floor on a platform made by placing timbers across the derrick girts. More often they are situated on a separate platform immediately outside the derrick.

The height to which gas traps should be elevated depends upon the location of the gage tanks and upon the well fittings and flow line from the tubing head. For efficient operation, the oil line from the top of the tubing to the gas trap should be free from right-angle bends and no part of the line should be horizontal. Abrupt changes in the direction of the flow of the oil and gas mixture from the well introduce friction and create back-pressures on the well. Horizontal lines allow the gas to separate from the oil and flow along the upper part of the line. Bypassing of the gas in the lead line from the tubing head to the gas trap decreases the over-all efficiency of the gas-lift. For best results the flow line from the top of the tubing to the gas trap should be goosenecked. In one instance, the daily production of a 350-bbl. well was increased to 366 bbl. by removing one 90° ell from the flow line between the tubing head and the gas trap and installing a gooseneck flow line in place of the horizontal line with its vertical riser.

Pressure and Volume-recording Devices

It is important that automatic recording gas meters and pressure gages be provided on the gas lines to the wells and on the gas discharge lines from the gas traps. The successful operation of the gas-lift method

of flowing wells depends in a large measure upon the volume and pressure of the gas delivered to the well. The data obtained from pressure and volume-recording devices are invaluable to engineers and others upon whose knowledge and skill depends the successful operation of the gas-lift. Continuous records of both static and differential pressures of the gas to and from the wells, recorded on 24-hr. charts, is the means of gaging the performance of the gas-lift. Without these records, operators work more or less in the dark, and inefficient operation usually results. The difference between the gas volume passing through the meter on the gas-discharge line and that passing to the well is the volume of gas coming from the oil sand and from solution in the oil. If there is no leakage of gas to low-pressure sands above the productive horizon in the well then the ratio of this differential gas figure in cubic feet per day to the volume of oil in barrels produced daily is the formational gas factor, better known as the gas-oil ratio.

Various types and makes of volume and pressure-recording devices are in use in the California fields. Each type is an orifice meter with a recording gage.

Where the central header control method of flowing wells by gas-lift is used, the pressure and volume-recording instruments on the gas intake lines to the wells are usually located in the header house. This arrangement makes it possible to operate the wells efficiently from this central location. At one installation in Southern California, one man per tour is taking care of over 20 wells, some of which are located a mile away from the header house. The outlet gas meters are always located at the gas traps where they measure the wet gas as it leaves the traps.

Casinghead Connections

Various types of packed casingheads are used in the casinghead or "Christmas tree" assembly on gas-lift wells in California. The most important requirements of the casinghead on a gas-lift well are that it be secure against leakage of gas and strong enough to support the string of tubing suspended in the well. Pressures of 900 to 1000 and more pounds per square inch are required to start certain wells flowing, so that it is essential that casingheads be designed and packed to withstand such pressures. The weight that may come on casingheads varies with the size and length of the tubing and whether or not the tubing is suspended off bottom. Strings of 2½ and 3-in. tubing 4000 to 5000 ft. long are common in the California oil fields.

The gas connections are usually so arranged that the gas may be introduced through the tubing or between the tubing and the casing. This arrangement allows the well to be "rocked" as described under the heading "Starting Pressures," until the fluid column in the eduction

tube becomes sufficiently aerated to start the well flowing with normal working pressure. For convenience of starting the valves in the gas line to the casing and in the bypass line to the tubing are located close together on the derrick floor at the casinghead.

All gas-lift wells in California however are not fitted for "rocking." Some operators rely entirely upon high gas pressure to start the flow of oil from the wells. This method of starting wells is successful where high-pressure gas from high-pressure or booster compressors is available and in wells where high starting pressures have no detrimental effect on the well. However, since the productive sands in many wells take gas at pressures less than that required to start the well flowing by introducing high-pressure gas, the only alternative starting methods used at such wells is "rocking" (reversing the gas flow), lightening the column of fluid in the tubing by swabbing, and raising the tubing. To subject wells to pressure higher than the rock pressure even for a short time is dangerous practice. Sediment in the oil often clogs the walls of the well or the walls become plastered with mud. Such wells must usually be cleaned to restore the drainage area to its original condition.

Cost of Installing Gas-lift Process

The cost of installing the process will depend largely upon the equipment already in use on the property. Usually gas traps, gage tanks and gas lines to dispose of the gas from the traps to gasoline plants are already installed at a well to take care of the production while it is flowing. Such equipment can usually be used for the gas-lift process without many material changes. As the gas-lift method of flowing a well is simply another method of pumping a well and is seldom used until after a well has stopped flowing naturally or shortly before, it is but a question of which method of pumping will give the largest return on the capital invested. Wells on the gas-lift usually produce more oil than would have been obtained in the same length of time by ordinary pumping methods and often the increase in gasoline recovered from the gas will pay all installation costs in 2 to 6 months.

Gas-lift pumping simulates production during the early life of a well. More oil is usually produced than could be raised by the ordinary oil field plunger pump. Where at some wells from 300 to 600 bbl. of oil was the maximum obtainable by ordinary pumping methods, the gas-lift has produced from 600 to 1000 bbl. a day for a long period.

For equipping wells to produce by the gas-lift method, there are necessary in addition to gas traps and gage tanks and other equipment of flowing wells:

1. A compressor plant, including gas engines or electric motors, compressors and accessories. If compressors are steam-driven steam boilers of sufficient capacity are required.

2. Pipe lines for distributing the compressed gas to the wells.

The costs of central compressor plants vary with the types and amount of equipment installed and with the character of the installation and construction. From a limited amount of data the costs of complete compressor plants of several types of equipment have been obtained. The costs of several complete plants erected recently in California vary from \$15 to \$25 per 1000 cu. ft. per day capacity. These costs include all compressor equipment, absorbers, piping, gages, buildings, etc.

Various sizes of compressors are used for flowing single wells. At some wells in California 8 by 4 by 8 in. straight-line, tandem, two-stage compressors having a piston displacement of 113 cu. ft. and rated at 500 lb. per sq. in. working pressure are used. At other wells, 12 by 6 by 12-in. duplex, two-stage compressors with a piston displacement of 312 cu. ft. are used, while compressors intermediate in size between the 8 by 4 by 8 and 12 by 6 by 12 in. are common in the California oil fields. The cost of one-unit compressor plants varies not only with the size of compressor installed but with the kind of motive power used to drive the compressor.

The cost of an electric motor-driven compressor plant, including an 8 by 4 by 8-in. straight-line, tandem, two-stage compressor, complete with electric motor, belt, foundations, piping and labor charges is about \$3500; when a 10 by 4½ by 10-in. compressor is installed the complete cost of the plant is about \$4500; and a 12 by 5 by 12-in. compressor installation with electric motor and accessories, including the cost of installing, is from \$5600 to \$6500.

Where gas engines are used to drive the compressors, costs of complete plants have been considerably more than plants of similar capacity operated by electric motors. On one property the cost of a one-unit compressor plant consisting of a 10 by 4½ by 10-in. duplex, two-stage compressor, driven by a 60-hp. gas engine was \$8050. This cost includes concrete foundations for the compressor and gas engine, belt, meters, gages, piping, and all labor costs.

A steam-driven 10½ by 5½ by 12-in. compressor with 8-in. steam cylinders, a 75-hp. fire box boiler, concrete foundation for the compressor, necessary accessories, and labor charges cost on one property \$6600.

Housing costs are not included in any of the above figures for one-unit compressor installations because they vary with the size of the building and the materials used in its construction. Also in many cases no building is constructed over the compressor plant.

Portable gasoline engine-driven units complete with 8 by 3½ by 8-in. straight-line tandem, two-stage compressor, 155 cu. ft. displacement capacity, rated at 500 lb. working pressure, belt connected to a gasoline engine with 5⅜-in. bore and 6¼-in. stroke, mounted as a unit on a 4-wheel steel-tired truck, costs \$4200 delivered in the Southern California oil fields.

Portable electric motor-driven compressor units with a capacity of 250 cu. ft. displacement, mounted on 4-wheel trailers cost complete, ready to operate, from $5000 to $6500, depending upon the size of the machinery and the kind and make of trailer. The higher figure is for an Ingersoll-Rand type X. R. B. duplex, two-stage compressor with high and low-pressure cylinder 12 by 12 and 6 by 12 in., respectively. The compressor is driven at 225 r. p. m. by a 100-hp. electric motor. The compressor and motor, together with starting controller, resistance grids, and all necessary gages are mounted complete as a unit on a 4-wheel solid rubber-tired trailer. This outfit will easily handle one 4000-ft. well making 1000 or more barrels of oil daily. When intake gas at pressures of 75 to 100 lb. per sq. in. is obtainable, this same outfit will handle two wells by using two 6 by 12-in. cylinders and operating the compressor as a single-stage unit.

Operating Costs

It is difficult to determine the actual cost of pumping oil wells by the gas-lift method when compressed gas is supplied by a central compressor plant. Operators usually charge to pumping costs only the cost of compressing the gas supplied to the well, giving the well no credit for the added gas returned nor for the additional amount of gasoline recovered. The generally accepted figure for the cost of compressing natural gas in large central compressor plants in California is from 3 to 5 c. per 1000 cu. ft. Plants with an output of 6,000,000 or more cubic feet of gas per day estimate the cost of compressing gas at 3 c. per 1000 cu. ft. In smaller central plants, the proportionally greater overhead and labor charges usually tend to increase the compression cost to 5 to 7 or 8 c. per 1000 cu. ft. of gas compressed.

The cost of lifting a barrel of oil varies with the volume of extraneous gas required to raise a barrel of oil to surface. On the basis of 3 c. per 1000 cu. ft. as the cost of compressing natural gas, some operator's lifting costs are not a great deal above 3 or 4 c. per bbl. The average lifting cost by the gas-lift method of a large number of wells using gas from a central compressor plant is about 8 c. per bbl. of oil.

One operator in the Southern California fields who operates 12 or more wells from a 5,000,000-cu. ft. daily capacity central compressor plant estimates that his company is flowing oil by the gas-lift method at from 5 to 7 c. per bbl. In figuring this cost, he estimates the depreciation of the compressor plant at 20 per cent. per year. In other words, the cost of the plant is charged off entirely within 5 years.

The cost of operating one-unit compressor plants having a capacity of 400,000 or less cubic feet of gas per day, varies from $25 to $40 per day, depending mainly upon the kind of motive power used. The lower figure is for a steam compressor, with the cost of operating an electrically

driven compressor about midway between these two extremes. Using the above figures as a basis, the cost of compressing 1000 cu. ft. of gas in a one-unit compressor plant varies from about 6 to 10 c. The cost of lifting a barrel of oil when one-unit compressor plants are used varies therefore from 6 to 20 or more cents with the average around 12 c. per barrel.

The lifting cost of 10 to 12° A. P. I. gravity oil at Cat Canyon, California, by the gas-lift method is about 14 c. per bbl., whereas it previously averaged nearer 45 c. per bbl. when the wells were on the pump. Not only has the lifting cost been reduced, but the production has been materially increased since the wells were placed on the gas-lift. The gravity of the oil has also been increased about 2° A. P. I. gravity, principally because the gas-lift has been instrumental in decreasing the sand cut from about 30 to 3 per cent.

[This paper was discussed in the General Discussion. See page 112.]

Air-gas Lift Practice in the Seminole Field

By S. F. Shaw,* San Antonio, Texas

(Fort Worth Meeting, October, 1927)

The Seminole field was first drilled in 1913. During the next 10 years other attempts were made to discover oil in this field, but without encouragement until March, 1926, when the Indian Territory Illuminating Oil Co. completed No. 1 Dyer in the Hunton lime for 1100 bbl. On July 16, 1926, the Independent-Garland interests discovered oil in the Wilcox formation when No. 1 T. Fixico came in at 4055 ft. and on Sept. 9, 1926, production reached a peak of 8040 bbl. On Aug. 1, 1927, the daily production of the pools making up the Seminole district amounted to slightly over 500,000 bbl., practically all of which was coming from the Wilcox formation.

The Hunton formation has not been very productive of oil, but has maintained a fairly high gas pressure; this formation has been encountered at from 3800 to 4200 ft., below which there is about 100 ft. of Sylvan shale. The shale is underlain by 75 ft. of Viola limestone in a few places in which formation oil has been encountered. Below the Viola lies the Upper Simpson formation in which is found the Wilcox sand. The depth of the Wilcox in the Seminole field varies from 3900 to 4500 ft., and initial production has reached as much as 12,000 bbl. The gravity of the oil is about 41° Bé.

The general practice is to set 6⅝-in. casing above the Wilcox and drill in, though in several cases 5$\frac{3}{16}$-in. casing has been set for the oil string, and in a few instances, casing as small as 4¾ in. has been employed.

Production Statistics

Production for the Seminole district for the various months since its discovery is shown in Table 1.

Table 1.—*Production in the Seminole Field by Months*

1926	Bbl.	1927	Bbl.
March	24,696	January	5,639,938
April	33,830	February	7,028,950
May	24,481	March	9,706,689
June	85,790	April	10,010,250
July	194,124	May	10,964,793
August	427,366	June	11,506,140
September	644,824	July	14,711,087
October	1,919,225		
November	3,312,281		
December	4,250,608		
Total, 1926	10,917,225	Total, 1927	69,567,847

* Consulting Engineer.

Production of the Carter Oil Co. in the Seminole field up to Aug. 1, 1927, is shown in Table 2.

TABLE 2.—*Production of Carter Oil Co. in Seminole Field*

1926	Total Bbl.	1927	Total Bbl.	Air-lift, Bbl.
July	1,550.40	January	920,428.83	58,600
August	67,249.18	February	1,252,191.23	739,900
September	44,374.09	March	1,565,330.00	987,900
October	62,154.82	April	2,461,749.08	1,267,500
November	149,813.96	May	2,332,499.73	1,098,600
December	569,881.11	June	2,305,642.84	1,236,400
		*July	1,981,537.50	1,276,900
Total, 1926	895,023.56	*August	1,598,850.00	1,209,700
		*September	1,504,549.00	1,173,000
		Total, 1927	15,922,778.21	9,048,500

* Estimated.

The relative importance of the air-gas lift in the Seminole field can be best realized by referring to Table 3. It will be noted that of the total production of 411,000 bbl. on June 27, 1927, there was produced by air-gas lift 275,000 bbl., or approximately 67 per cent. The air-gas lift production in Seminole alone on June 27, 1927, was approximately 11 per cent. of the daily average production of the entire United States.

Compressor Plants

Two general types of compressors are in use in this field, one being a small electric or gas-motor compressor, the other is a larger type usually direct driven from gas engines, though there are a few installations of the larger type driven by belts from gas engines. The sizes and makes of compressors of the small type mostly employed are as follows:

Manufacturer	Size, Inches	Displacement, Cu. Ft.	R. p. m.
Ingersoll-Rand Co	9½ by 4 by 10	243	300
Ingersoll-Rand Co	10 by 4¼ by 10	270	300
Chicago Pneumatic Tool Co	10 by 4¼ by 10	242	275
Worthington Pump & Mach. Corp	10 by 4¼ by 12	270	250

TABLE 3.—*Production in Various Pools of the Seminole Field, June, 1927*

Company	June 6 Total Bbl.	June 6 Air Gas Lift	June 13 Total Bbl.	June 13 Air Gas Lift	June 20 Total Bbl.	June 20 Air Gas Lift	June 27 Total Bbl.	June 27 Air Gas Lift
Bowlegs Pool.								
Amerada Pet Corp.	11,715	11,715	10,140	10,140	11,070	11,070	11,940	11,940
Atlantic Oil Prod Co	7,693	5,534	9,764	6,084	7,702	6,247	10,590	10,590
Barnsdall Oil Corp.	1,028	—	267	—	80	—	643	
The Carter Oil Co.	20,015	12,105	23,800	23,800	23,675	20,505	22,445	19,700
Empire	7,228	7,223	6,274	6,274	5,580	5,484	6,741	4,001
Gypsy Oil Co.	4,117	3,835	4,364	4,064	4,770	4,533	4,674	4,584
Independent Oil & Gas Co.					1,215	1,215	1,350	1,350
Indian Territory Illum Oil Co.	44,832	39,212	46,429	45,422	51,670	49,490	54,503	52,334
McCullough	440	—	—	—	—	—	1,202	1,202
Mid Continent Oil & Gas	2,463	1,643	2,338	1,258	3,102	3,102	2,696	2,696
Minnehoma	977		2,456		2,867	2,108	2,678	2,678
Prairie Oil and Gas Co	9,215	8,990	9,026	7,279	9,425	9,425	9,460	9,460
Pure Oil Co.	12,057	11,873	14,370	14,141	17,840	17,289	26,823	26,823
Roxana Petroleum Corp	1,286	575	1,580	992	1,750	709	2,250	1,917
Shaffer Oil & Refining Co						2,883	2,069	2,069
Sinclair Oil & Gas Co.	12,730	6,225	14,065	12,315	14,330	13,980	14,075	13,340
The Texas Co.	4,745	1,145	5,730	2,330	1,925	1,925	5,771	5,771
Tidal	1,675	1,675	1,585	1,585	—	—	1,490	1,440
Total	142,206	109,750	151,677	134,679	157,001	152,965	181,400	171,945
Earlsboro Pool.								
Amerada Petroleum Corp	12,108	535	11,284	509	10,487	1,640	9,742	1,247
Barnsdall Oil Corp	7,256	1,043	7,042	847	13,088	1,040	10,474	561
The Carter Oil Co.							6,095	
Crosbie	3,370		3,280		2,940		2,715	
Empire					10,500		9,295	
Gypsy Oil Co	8,446	1,931	10,388	9,649	7,608	7,593	9,418	5,781
Independent Oil & Gas.	2,350		2,232		1,942		3,284	
Interocean	350		210		570		512	
Magnolia Pet. Corp.	19,373		22,549		27,195		23,905	
Mid-Continent Oil & Gas	3,995	580	8540		4,175	3,130	3,820	895
Phillips Pet. Co.	2,000	340	1,912	375	2,420	1,050	1,187	1,187
Phil-Mac	1,117	875	582	517	391	300	225	225
Prairie Oil & Gas Co	245	245	275	275	4,150	155	10,915	
Sinclair Oil & Gas								
The Texas Co	445		442	442	395		325	
Total	61,054	5,549	68,736	12,614	85,859	14,911	91,912	9,846
Searight Pool.								
The Carter Oil Co	16,815	2,974	16,985	4,915	16,190	2,500	14,759	2,340
Gypsy Oil Co.	672	765	615	672	535	535	530	530
Mid Continent Oil & Gas	6,785	6,745	6,560	6,500	5,770	5,700	5,740	4,875
Prairie Oil & Gas Co.	5,215	5,020	5,480	5,400	5,036	4,965	3,535	3,420
Pure Oil Co	854	—	858	—	1,487	—	850	—
Roxana Pet. Corp.	208	—	4,368	—	3,598	—	3,372	—
F.J. Searight	—	—	—	—	—	—	—	—
Sinclair Oil & Gas Co	1,080	1,080	1,035	1,035	2,600		2,600	—
Twin State Oil Co	975	975	1,040	—	930		1,217	—
Wilcox Oil & Gas Co	1,945		3,525	1,650	2,386	1,600	2,536	2,596
Total	34,549	17,559	40,446	20,172	38,530	15,300	35,139	13,701
Seminole City Pool.								
Amerada Petroleum Corp	4,011	3,541	4,020	3,847	3,937	3,689	3,386	3,367
Atlantic Oil Prod Co	440	—	420	—	960	—	910	—
Barnsdall Oil Corp.	8,069	7,024	6,977	6,732	6,072	5,677	6,037	5,907
The Carter Oil Co	37,032	20,965	37,427	15,807	32,535	16,386	29,383	16,458
Empire	1,637	—	3,508	3,218	3,834	3,127	3,102	2,875
Gypsy Oil Co	6,987	6,208	5,670	4,981	7,383	4,987	7,215	4,684
Independent Oil & Gas	2,659	1,613	2,820	2,742	2,159	2,159	2,484	1,883
Indian Territory Ill. Oil Co	7,109	6,922	6,840	6,574	6,888	6,675	6,789	5,541
Kingwood	2,700	736	2,560	1,907	2,461	1,825	2,270	1,696
Magnolia Pet. Co	1,902	598	1,572	1,572	2,012	800	1,364	1,364
Mid-Continent Oil & Gas	2,845	2,845	2,630	2,630	2,245	1,715	2,210	2,210
Mid-Kansas	860	860	749	749	769	738	833	788
Philmack	1,410	1,410	835	835	800	800	1,725	1,725
Phillips Pet. Co.	1,725	1,725	1,072	1,072	1,317	1,042	800	800
Prairie Oil & Gas Co.	4,112	3,587	4,155	2,155	3,901	3,130	3,907	3,242
Pure Oil Co.	9,849	9,849	8,968	8,938	8,167	7,960	7,763	7,440
Roxana Pet. Corp.	963	893	828	759	598	532	722	722
Sinclair Oil & Gas	4,170	2,410	3,957	2,937	4,145	2,295	3,890	3,810
T. B. Slick.	6,458	4,325	6,196	4,170	4,651	3,651	4,378	4,214
Superior	2,127	—	2,313	—	2,318	—	2,108	—
The Texas Co.	50	—	30	—	32	—	31	—
Tidal	8,010	7,650	7,987	7,567	7,463	5,033	8,735	8,365
Turman Oil Co.	7,489	641	4,983	4,983	4,461	1,411	3,887	2,774
Total	122,474	83,802	116,439	83,876	108,708	73,831	107,929	79,837

Makes and sizes of the larger types of compressors mostly employed in this field are as follows:

Manufacturer	Size, Inches	Displacement, Cu. Ft.	R. p. m.
Bessemer Gas Engine Co	9¾ by 5 by 20	311	180
Bessemer Gas Engine Co	13½ by 6¼ by 20	585	180
Bessemer Gas Engine Co	14¼ by 6¼ by 20	653	180
Clark Bros	14 by 7¼ by 20		
Clark Bros	15 by 7¼ by 20		
Cooper	14½ by 7½ by 20		
Cooper	16 by 7¾ by 20		
Cooper	10 by 5½ by 20		
Ingersoll-Rand Co	15 by 6¾ by 16	486	150

At the end of July, 1927, the various plants of the Carter Oil Co. consisted of the following compressors:

Make	Size, Inches	Number of Compressors	Drive
Ingersoll-Rand Co	9½ by 4 by 10	185	100-hp. elec. motor
Ingersoll-Rand Co	10 by 4¼ by 10		100-hp. elec. motor
Chicago Pneum. Tool Co.	10 by 4¼ by 10	2	75-hp. elec. motor
Worthington P. & M. Co.	10 by 4¾ by 12	4	100-hp. elec. motor
Bessemer Gas Engine Co.	13½ by 6¼ by 20	58	165-hp. gas engine direct

The Ingersoll-Rand compressor driven by electric motor has been found to be the most satisfactory, owing to the greater flexibility and dependability of this type of compressor, particularly in the early stages of air-gas lift operations. After pressures have declined to a low point, and it has been desirable to operate the wells by gas rather than by air, the Bessemer compressors driven by gas engines have been quite serviceable, and the cost of compression per 1000 cu. ft. of gas or air is considerably less than when using the electric motor-driven type

Operations of the Carter Oil Co.

The first well of the Carter Oil Co. to be operated by air-lift was No. 1 B. Carter which was placed on air-lift Oct. 22, 1926, for testing purposes. A 5 by 15-ft. trap was placed close to the well, and an increase of about 50 per cent. obtained. This work was done with two Ingersoll-Rand 8 by 3¼ by 8-in. portable compressors.

Other wells were placed on air and gas-lift from time to time so that 63 wells had been equipped and operated by this method by June 30, 1927. On June 30, the air-gas lift production of the Carter company was 42,077 bbl. out of a total production of 72,297 barrels.

AIR-GAS LIFT INSTALLATIONS

The general method followed in equipping a well is shown in Fig. 1. In the early stages of production when the wells were large producers,

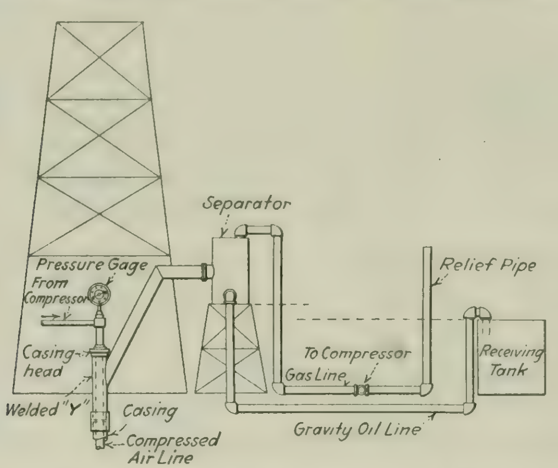


FIG. 1.—DISCHARGE ARRANGEMENTS FOR SHAW METHOD OF AIR AND GAS-LIFT APPLICATION.

the general arrangement at the top of the well that was found to be most serviceable is shown in Figs. 2 and 3. The practice was adopted of

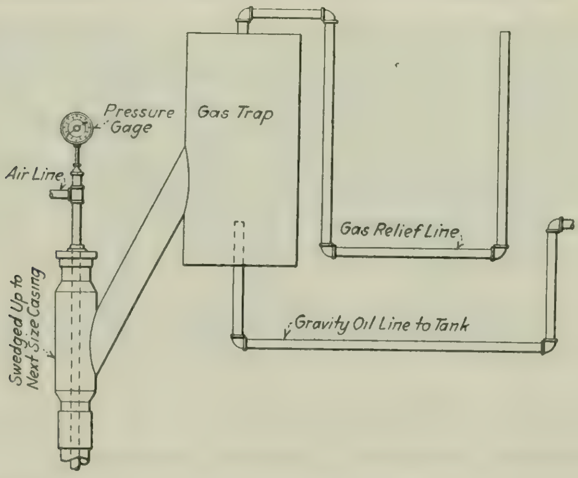


FIG. 2.—GENERAL ARRANGEMENTS AT TOP OF WELL WHEN FLOWING BETWEEN CASING AND TUBING.

equipping each well with input and output meters. The general arrangement of pipe connections for the output meter is shown in Figs. 4 and 5.

All of the wells thus equipped had the air-gas tubing lowered inside the casing, and the oil was lifted through the annular space between the

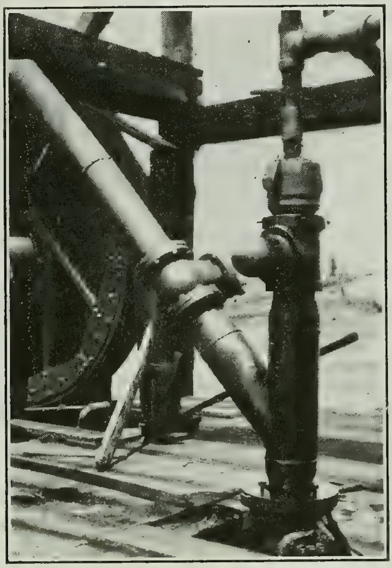


FIG. 3.—ARRANGEMENTS AT NO. 4 WISE, BOWLEGS POOL.

casing and the tubing. After the wells had declined in production to from 400 to 100 bbl., a string of tapered tubing was inserted in the well and the oil flowed through the tubing in order to economize in the use of compressed gas.

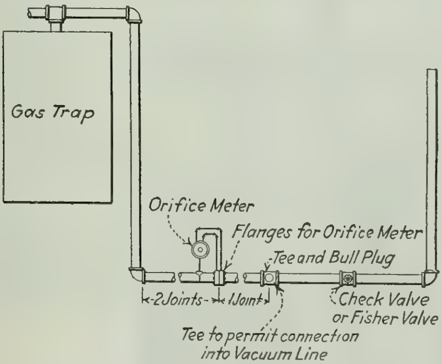


FIG. 4.—PIPING CONNECTIONS FOR OUTPUT ORIFICE METER.

FIG. 5.—OUTPUT ORIFICE METER ON NO. 6 DAVIS WELL, SEARIGHT POOL.

The arrangement at the top for starting wells with high pressures when using tapered tubing is shown in Figs. 6 and 7. Two types of

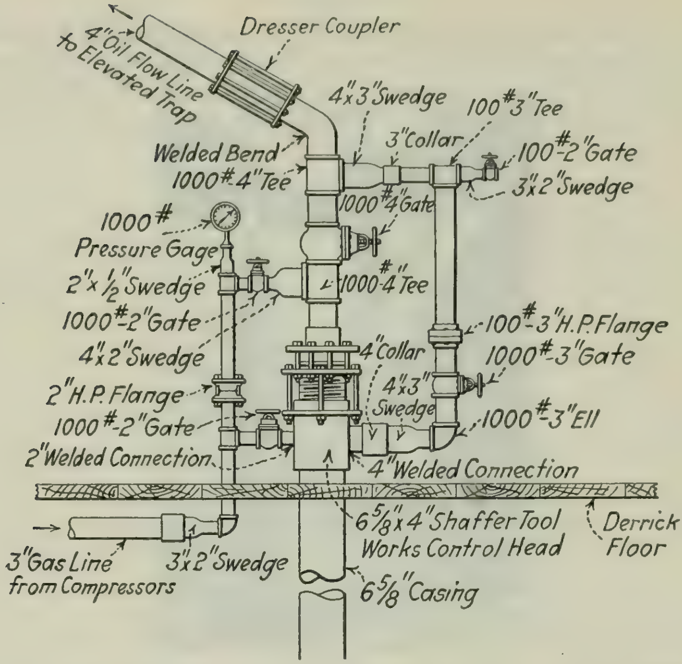


Fig. 6.—Layout at top of well for flowing through the tubing.

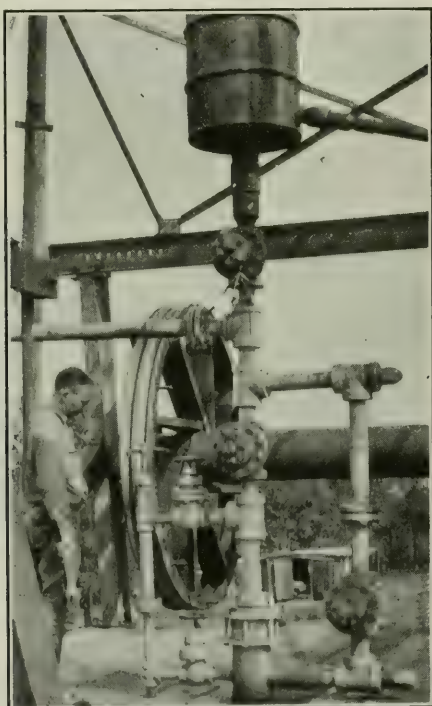


Fig. 7.—Arrangements at No. 1 W. E. Grisso, Seminole pool, for flowing through tubing.

8

9

10

Fig. 8.—Top arrangement of No. 2 G. F. Killingsworth Seminole, flowing between casing and tubing.

Fig. 9.—Top arrangement of No. 6 W. E. Killingsworth, Seminole, flowing between casing and tubing.

Fig. 10.—Manifold at No. 1 Grisso lift station, Seminole pool.

top arrangement for wells of the Carter Oil Co. are illustrated in Figs. 8 and 9. Traps were placed close to the well, and all right-angle bends feasible to remove were eliminated, as was done at Tonkawa and Braman last year, which resulted in notable increases of production. It became the practice of the Carter Oil Co. to equip wells flowing naturally with trap in this manner, and in four cases, increases of 2000 bbl. per well per day or more were obtained by this change alone without the aid of compressed air from the compressors. It should not be assumed, however, that placing the trap close to the well will always result in increased production, since this will be governed largely by the conditions obtaining for each individual well.

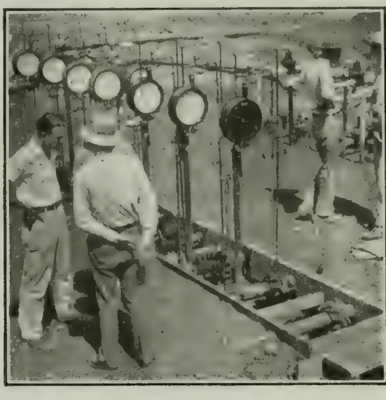


FIG. 11.—FOXBORO VOLUMETRIC CONTROL METERS ADDED TO MANIFOLD SHOWN IN FIG. 10.

In the early stages of operation where several wells were operated from one compressor station, a manifold header was employed, as shown in Fig. 10. Later, when it was desired to operate the plant with volumetric control on small wells, the control meters were connected up through the same manifold as shown in Fig. 11. In this way every desired degree of flexibility was provided for, in starting and operating the various wells.

DEPTHS OF WELLS AND PRESSURES EMPLOYED

Wells have averaged about 4100 ft. in depth. The highest pressures in starting were about 1000 lb. per sq. in. and since the small compressors are built for this pressure no trouble was encountered in meeting these high pressures. High-pressure fittings are employed altogether. The highest working pressures were about 450 lb. which, of course, declined gradually with the age of the well. The lowest pressure employed was about 50 lb. on a small well making about 10 bbl. per day, equipped with a string of tapered tubing.

Back-pressures

In some fields it has been of advantage to use "beans" or "chokes" in the flow line, thereby securing a high back-pressure and for a short time conserving gas, but it was found at Seminole that the wells in many cases would cease to flow where any form of back-pressure was applied. The lowering of a string of 2 or 2½-in. tubing caused many a large well to cease flowing. The use of a bean is of advantage only where pressures are high, thus causing the well to act more in the nature of an artesian flow rather than as a gas-lift. In this case the fluid level stands very high and the oil is "squeezed" through the bean; production is greatly reduced. As soon, however, as the pressure has declined and the fluid level reduced to a point where the well is acting mainly as a gas-lift, a bean causes the gas-oil ratio to increase to a high point. This effect is clearly shown by the results of the work of the Shell Co. at Dominguez, Calif. The same effect of conserving the gas can be secured by employing the proper size of tubing through which to flow the well, and the gas-oil ratio does not then increase to excessive points when the fluid level is lowered.

Examples of Air-gas Lift Wells

The graph in Fig. 12 shows the production curve of No 2 Grisso well in the Seminole pool, arranged in averages of 10-day periods. This well was one of the early wells of the Carter Oil Co. to be placed on the air-lift. Up to June 30, this well had produced a total of approximately 585,000 bbl. The production curve shows a drop from the normal between the dates of Feb. 16 and 28, caused by curtailment of production. When the well was again operated at maximum capacity the curve was restored only to the point at which it would appear to have declined had there been no curtailment, hence there was a loss of production of approximately 20,000 bbl. from this well during that period. The lower end of the production curve tends to flatten, and it is possible that a fairly well settled production can be expected from this point unless there is an encroachment of water, which would cause a rather sudden drop. The input pressure, starting at 410 lb. per sq. in., has declined as was to be expected. The gas-lift factor has shown a rather rapid rise in cubic feet per barrel of output gas from the well toward the last periods noted. The gas-oil ratio, obtained by subtracting the input gas per barrel from the output gas per barrel, shows a fairly regular increase to May 27, when it began to decline. It has been noted on some occasions that this decline in the gas-oil ratio indicated the approach of water encroachment. The decline in the gas-oil ratio must be made up by input gas in order to maintain the maximum production of oil from the well.

Fig. 13 contains curves of the various data for No. 1 Bowlegs well in the Bowlegs pool. The sudden drop in the early stage of production appeared to be a natural decline; the well was shot, after which the curve rose to the point shown at May 29. The input gas pressure has not

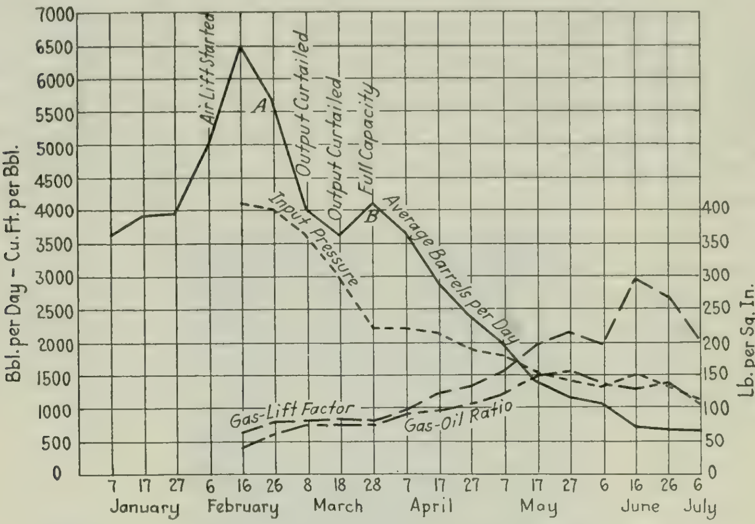


Fig. 12.—Production curve of No. 2 Grisso, Seminole pool.

declined greatly as yet, and the gas-oil ratio has held at a fairly low point; that is, under 500 cu. ft. per bbl., which is one of the lowest gas-oil ratios at any of the wells of the Carter Oil Co. in the Seminole district.

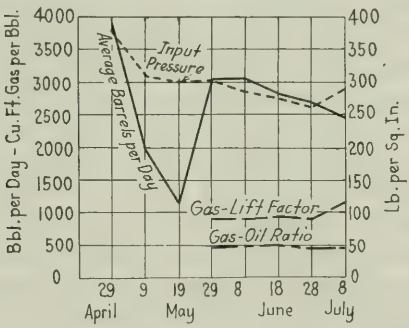


Fig. 13.—Various data for No. 1 Bowlegs, Seminole district.

The gas-lift factor has been rather low, though on July 8 there appeared to be a tendency toward an upward bend in this curve. A test was run on this well on May 27 and the best operating efficiency was found to be 21 per cent.

Small Wells Operated by Air-gas Lift

Considerable difficulty has been experienced in pumping small wells on the beam in the Seminole field, and the writer was requested to determine whether these wells could be operated by means of the air-gas lift. Two wells were equipped with tapered tubing to determine whether this was practicable. The results were quite satisfactory and subsequently several other wells were equipped in this manner with fully as good or better results than for the first wells. One well with a production as small as 10 bbl. per day was operated very satisfactorily, and several wells ranging from 20 to 350 bbl. are now being flowed in this manner. The quantity of oil lifted per day was not increased except in one instance, but the quantity of gas sent to the well has been reduced to about one-half the consumption formerly employed when lifting between the tubing and casing.

As wells become smaller in production, the pressure drops, the lift increases, and the quantity of gas required to lift a barrel of oil is greatly increased over that necessary for a large well, and this quantity increases to an abnormal extent if the lifting be done through the same eductor as when flowing a large well. A consumption of 50,000 cu. ft. per bbl. could easily be reached in flowing a 10-bbl. well through the annular area between the 2 or 2½-in. tubing and the 6⅝-in. casing, whereas a proper size of taper tubing would operate on 10,000 cu. ft. per bbl. or less, at 50 lb. pressure per sq. in., when flowing a well of this size.

The conditions of pressure or submergence of lift, quantity of fluid, and quantity of gas accompanying the oil have a close bearing on the proper design of tapered tubing, and unless a nearly correct design is obtained it is best not to use this method of tubing since the quantity of gas consumed per barrel of oil may become excessive and production may be considerably reduced.

When small wells are operated by gas-lift the lifting costs become a matter of great importance. If the small electric-driven compressor that was employed for high pressures be employed for small low-pressure wells, the cost per 1000 cu. ft. of compressed air or gas will probably reach 7 or 8c., and at 10,000 cu. ft. per bbl. the cost would reach 70 to 80c. with no allowance for interest or depreciation. On the other hand, gas can be compressed in a compressor direct driven from a gas engine at a cost of 3 to 4c. per 1000 cu. ft. and the lifting cost then becomes 30 to 40c. per bbl., which is considerably lower than would be the cost of a well on the beam, where frequent stoppages are caused by rod breakage, leaky valves, etc.

We have operated a small well by compressor for 60 days without loss of production for a single day. If now we consider the cost of lifting oil in a well of 100 to 200 bbl. per day, total depth of 4000 ft. operated by

air-lift and equipped with tapered tubing of proper design, we would have a gas input consumption of about 2500 cu. ft. per bbl., which at 3 to 4c. per 1000 cu. ft. would be 7½ to 10c. per bbl., and there would be very infrequent loss of production due to stoppages.

It has been demonstrated that with efficient design of air-gas lift, the production of wells can be increased much beyond that obtained with the former type of air-lift employed; also that small wells can be operated by air-lift with tapered tubing at a cost that places this method in competition with beam pumps in many fields. The next step in conservation that the writer expects to have an opportunity to demonstrate is that of restoring the pressure in a pool and producing by air-gas lift all of the oil possible to lift economically. This combined operation is probably the method toward which we shall eventually be working in recovering the maximum quantity of oil from pools where the oil is recovered through bore holes.

General Discussion on the Air-gas Lift

H. P. Porter,* Tulsa, Okla.—The papers presented at this meeting contain a great amount of valuable information. Wonderful progress has been shown in the development of air and gas-lifts. There has been nearly everything brought out that touches upon the subject. The real point that is lacking is exact knowledge of the velocity within the flow column which will produce the best effect—that is the thing we must know more about.

Velocity in Gas-lift Flow

In other lines of industry the matter of velocity of fluids in pipe lines has been well analyzed and there are known laws by which to calculate velocity of flow; for instance, in irrigation work large pumps are designed with intake pipes to employ an intake velocity of 4 ft. per sec. By reduced cross-section the velocity is increased rapidly as it enters the pump and the discharge rate is at 12 ft. per sec., which in turn is reduced in the discharge column to 4 ft. per sec. Crushed coal, grain and granular material is found to be best conveyed by air when a pneumatic conveyor is employed at 100 ft. per sec. As in the design of a pumping plant or a pneumatic conveyor, the velocity at the lower end of the column in the flowing well must be controlled within certain limits for best results.

Mr. Griswold, I believe, stated that they had velocity as low as 15 ft. per sec. and from that up to 75 ft. per sec.

Mr. Pierce and Mr. Lewis showed an ideal flow column showing how the velocity increased as the fluid was carried up the column, but did not give any figures as to the velocity. It would be well to take that sort of a diagram to establish an ideal velocity at the lower or intake end, and then calculate the velocity from expansion of the gas as it goes up. It may be that the ideal intake velocity would vary, depending on the depth of the well, the quantity of liquid to be handled or the pressure which it may be desired to hold. The subject is one that might be worth much research.

---

* Gypsy Oil & Gas Co.

A. C. Rubel,* Compton, Calif.—I agree with Mr. Porter's suggestion. We have mines which approximate in depth the average depth of an oil well. It would not be beyond experimental possibilities to set up in mine shafts an "oil well" and determine the factors we need, just as pipe-line formulas have been determined.

Now we calculate from premises of which we are not sure. In the rising column of oil, we have such a different relation of oil and air, such a different resistance to flow, etc., that I question whether any calculation based on assumptions will be valuable. Work such as the Bureau of Mines has done is valuable. Let's carry this on and find out just what we want.

E. H. Griswold,† Ponca City, Okla.—I have spent some time and effort in an attempt to analyze the flowing conditions of wells and work out some formula which might be applicable in designing properly sized tubing strings. Under average conditions it would seem, by comparative volumes, that an excess of oil to gas occurred in the lower portion of the hole with the reverse condition at the top. The lower part of the flow column would be moved by an aerating effect and the upper part by a purely velocity flow, the gas carrying drops of oil, somewhat as a river carries sand.

Curves are available from refinery experiments showing the size of drops of oils of various gravities that may be carried by different velocities of gas. However, since it seems impossible to control or even measure the size of the drops in a flowing oil well, the purely mathematical analysis is of no present value. It would seem that extensive experimental data must be gathered before any real understanding of the problems will be obtained. This work of the Bureau of Mines will be of the utmost value.

E. V. Foran,‡ Fort Worth, Texas.—The velocity of the gas in the tubing is one of the biggest factors in production. Between several velocities, that giving lowest pressure on the base of the sand gives maximum production. But what may be a highly efficient velocity in one well may be inefficient in another. I think we can sacrifice efficiency in velocity, as in gas-oil ratio, if it gives us more barrels of oil. One rate might be best mechanically but its result on the base of the sand should be considered. I doubt if it will be possible to lay down a standard rule.

H. P. Porter.—I don't want to emphasize the point that mechanical efficiency is our problem. I think velocities could be determined very well and as to the pressure on the sand this could be taken into account and a velocity suitable to that condition and to the mechanical problem could be used.

When to Put a Well on Gas-lift

E. O. Bennett,|| Fort Worth, Texas.—With regard to the point as to where we will quit the gas-lift and go to the pump. Our results seem to indicate that with the gas-lift we have better control of the gas factor than on the pump. Clean-out jobs are also eliminated when production is maintained by the lift and this point is an important one in determining the economic balance.

On the other hand, we know that running machinery to compress gas costs more than running pumps—with the possibility that we will get a greater ultimate recovery if the gas-lift is not used as a blowing machine but as a means of control. Have you any data to show when to put a well on the gas-lift or pump?

* Petroleum Engineer, Union Oil Co. of California.

† Marland Oil Co. of Oklahoma.

‡ Production Engineer, Marland Oil Co. of Texas.

|| Chief Petroleum Engineer, Marland Oil Co. of Texas.

Member.—In a number of cases we watched a well's decline and when production got low we tried a combination of tubing, with poor results. We have taken wells off the gas-lift and put them back on the pump and have obtained a pronounced increase in production.

A. C. Rubel.—I think that this is entirely a matter of economics. The time to take a well off the gas-lift and put it on the pump is when you can make more money pumping than by flowing with gas. It will depend entirely on conditions in the hole.

In deep wells and crooked holes, as in the Rosecrans field of California, it is possible in most wells to pump at a greater rate than to flow by gas-lift, but it takes about one rod crew per well to keep the wells on the pump, on account of rod troubles, etc. On the gas-lift we are able to produce every day of the month and twelve months per year. To produce a well depth for depth along an offset line, in this field, the pumping cost will be about 62 c. per bbl. compared to about 23 c. per bbl. on the gas-lift. This is true because it takes much additional labor and material to keep the wells on the pump.

If the holes were in shape to pump, it would be more economical to pump them, but since they are not, the gas-lift is employed as a matter of cost consideration.

J. B. Umpleby.—What size of wells?

A. C. Rubel.—These wells will average less than 100 bbl. Trying to pump them, we wear holes in the tubing, sand up the wells, have rod troubles and everything it is possible to have in a pumping well. That is the reason we can flow them on gas-lift more cheaply than by pumping.

E. O. Bennett.—I would ask about controlling back-pressure on the pumping well by the amount taken out of the casinghead? Is it not highly dangerous to control a well in that way?

Member.—You can measure efficiency by dollars returned to dollars expended.

Control of Gas-oil Ratios

C. E. Beecher,* Bartlesville, Okla.—Is there any advantage in holding back-pressure on the sand? Can you not obtain that same back-pressure by control of the fluid level, eliminating crooked holes?

E. V. Foran.—The well referred to in my paper is surrounded by pumping wells. We are offset on two sides by other operators holding only atmospheric pressure on the sand. Under those conditions the input pressure of 49 lb. is the approximate pressure against the sand. There is certainly a point where, if we are to enlarge the drainage area of this well, we must find a way to maintain a lower pressure against the face of the sand. I believe if it is placed on the pump and the stroke shortened up to take the same amount of oil from the sand, we can carry the gas-lift principle on the pump. I see no reason why this cannot be done. This can be determined by experiment. If we are to measure recovery efficiency, we must measure efficiency on the pump against the lift. Why the gas ratio on the lift is lower than on the pump, I do not know. There is certainly a limit to holding too high a pressure on the sand.

E. O. Bennett.—I suggest we call on Mr. Vance, who has done considerable work along this line.

H. Vance,† Big Springs, Texas.—Gas-oil ratios can be controlled in pumping wells by raising pumping fluid levels, or holding pressure at the casinghead, or both.

---

* Production Engineer, Empire Gas & Fuel Co.

† Marland Oil Co. of Texas.

The cheapest and easiest way to control the gas-oil ratio, however, is by holding pressure at the casinghead.

Pumping wells producing considerable gas should be equipped with a good gas anchor. The total gas produced with the oil should be used for calculating the gas-oil ratio, although with the use of a gas anchor the casinghead gas alone will closely approximate the total volume and can be used for practical purposes.

In the chalk field in Howard County, Texas, there is one lease entirely equipped with small back-pressure regulators constructed from 1-in. globe valves. There has been a very noticeable decrease in the decline of the lease since the gas-oil ratio has been reduced by the use of these regulators.

In certain wells we have found that raising the pumping fluid level not only decreased the gas-oil ratio but reduced the cutting of cups by sand.

The logs of the wells should be studied and the position of the well on structure considered before effort is made to decrease the gas-oil ratio.

The gas-oil ratio can be controlled on gas or air-lift wells, pumping wells and natural flowing wells. Gas or air-lift wells give the closest and easiest control, while natural flowing wells offer the most difficulties.

A. W. Peake,* Casper, Wyo.—Something has been said about the formation gas-oil ratio being decreased by the use of gas-lift—that being an indication of greater ultimate recovery. Are there figures for decreased gas-oil ratio in wells on the flowing stage, or intermittent stage and on the pumping wells? What is the difference in the formation gas-oil ratio with the gas-lift and without?

E. O. Bennett.—I have some data on a chart accompanying a later paper that will partly answer the question.[1]

E. V. Foran.—I believe Mr. Peake has in mind some work in the Salt Creek field during the last three or four years. In addition to what was done there, I have some answers to his question in Jones County. There a well flowed at 50 lb., while on a near-by pumping well it took as high as 400 and the natural ratio of the wells in the sand only proved to be 90 cu. ft. to the barrel, while after being on the pump for a while gas was discharged at a higher rate than when on the gas-lift.

A. W. Peake.—I would like to be convinced about the greater ultimate recovery due to the decrease in the formation gas-oil ratio. In connection with the cost of gas-lifting oil as compared to pumping, some of the papers mentioned quoted figures without depreciation. Another paper mentioned $15,000 to $20,000 for installation cost. I wonder if the fact that the investment has to be eaten up sooner or later was considered in figuring the lifting cost.

Size of Wells Benefited by Gas-lift

E. G. Gaylord,† San Francisco, Calif.—The range in size of wells in which the gas-lift has a beneficial influence on production has been investigated in the Huntington Beach town lot area in California. Comparison of the average rate of decline of a group of wells on the gas-lift with that of a similar group made up of wells flowing naturally and later on the pump disclosed the following conditions:

Wells above 300 bbl. per day on the gas-lift showed a markedly better sustained production than wells similarly located which were flowing naturally or were on the pump.

---

* General Superintendent, Production Dept., Midwest Refining Co.

[1] See page 158.

† Standard Oil Co. of California.

Wells between 200 and 300 bbl. per day showed a slightly better sustained production due to the gas-lift, while below 200 bbl. the rate of decline of the gas-lift wells was more rapid than of the wells on the pump.

The production range covered in the above comparison included the normal flowing period of the average well, the transitionary stage between flowing and pumping and a portion of the pumping history.

The wells that had been flowing naturally ceased flowing when the production had declined to about 200 bbl. per day and were placed on the pump.

These results would seem to indicate that for this particular area use of the gas-lift is not warranted after the time when the production can be handled economically by a standard oil-well pump. By economically, I mean without too much sand and rod troubles, etc. Cost data indicate that the pumping costs per barrel are lower than the gas-lift costs, so we have an additional reason for discontinuing the use of the gas-lift at this time.

Does Gas-lift Exhaust Wells?

W. van der Gracht,* Ponca City, Okla.—We have heard some interesting data comparing yield of California wells on air-lift and on the pump. What information is there regarding the Seminole district or other areas in the Mid-Continent, as to what the wells will yield after they have been continued on the gas-lift during the period that under the old methods they would have been on the pump? When the point is reached where the gas-lift is no longer economical, and these wells are put on the pump, what is the experience as to the yield of those wells?

Are there any data from which we could approach a conclusion as to whether a long maintenance of air-lift or gas-lift on a well would have the effect of drawing in bottom or edge water more rapidly? Are there any such data for wells near the edge of a pool, or where there is bottom water in the producing formation?

C. D. Watson,† Tulsa, Okla.—The first thought perhaps of Dr. Van Der Gracht was a comparison between pumping wells and gas-lift wells. I might give some light on that by saying we have had some 19 wells on the pump which are comparable to 22 that are on the lift. These 22 wells are equipped with graduated tubing, and their average production is approximately twice that of those on the pump. The 22 lift wells made an average of 125 bbl. per day, while the beam wells over the same period made 51 bbl. per day.

Because of the condition of the sand and the crookedness of the holes, I think most of the operators in Seminole are aware that it is very difficult to pump wells. The oil recovered by lift at Seminole has been about 50,000,000 bbl. from 900 wells. This is considerably more than could have been taken out by the pump to date, under present pumping conditions. I believe it would have been necessary to pump these wells for several years before equaling this amount.

Answering the question which Mr. Bennett and others have asked regarding the economical point at which the well should be taken from the lift and placed on the pump again: It has been our experience that with the use of graduated tubing and intermittent flowing, we have been able to operate wells economically to lower than 20 bbl.—to perhaps 10 bbl. per day—and this cannot be done economically by the pump, considering the adverse pumping conditions of Seminole.

We have one well flowing 7 bbl. a day by stop cocking, using tapered tubing. This is being done economically.

---

* Marland Refining Co.

† Carter Oil Co.

W. van der Gracht.—That is not quite an answer to my question. These data emphasize that for a number of wells you have continued to use the gas-lift in the third stage of the production of the well, when otherwise it would have been on the pump.

My question is: Are there observations to show that there is any oil left to pump, after the gas-lift has ceased to be economical? Do you still get normally economical wells on the pump, or has the gas-lift taken out all the oil that was commercially recoverable?

This will vary, of course, for wells and for fields, and will depend on how long gas-lift was maintained. Can you take all the commercial oil out by gas-lift and leave nothing pumpable? In other words, will the entire settled period of a well, at least in some cases, which would have lasted many years, be concentrated in a few months of gas-lift production?

In California this would not be so noticeable, because the impregnated zone is so enormously thick, but where there is just one sand horizon, as at Seminole, is there any indication of what will happen in this respect? It is most important for the calculation of future expectations.

C. D. Watson.—In the end I think it will be found that it would take many years to exhaust a pool on the pump under present conditions, whereas it will probably have been exhausted in much shorter time with air-lift. However, I think that we have not yet reached a point on any wells where gas-lift is no longer economical.

B. A. Boatright,* Borger, Texas.—I believe we have some data that will answer Dr. Van Der Gracht's question. Marland's Whittenberg A-9 in the Panhandle district was put on the gas-lift in December, 1926, at which time the well was making 450 bbl. a day, and showed almost a straight-line decline curve until Oct. 1, 1927, at which time the production from this well was 110 bbl. The curve on this well shows a much slower decline than the average curve for this district.

The well was cleaned out and put on the pump. It started making approximately 100 bbl. a day, gradually increasing until at the present time it is making over 150 bbl. a day.

The gas-lift gave us an abnormally slow decline for nine months. After the point was reached where the gas-lift was not economical, the well was put on the pump and produced more oil than had been obtained by the lift method for some time previous.

In other words, we found that there is still oil that can be obtained and profitably produced by pumping after the lift has reached the economic limit as a producing method. As Mr. Watson said, it takes a longer period of time to get the same amount of oil from a well by pumping than by gas-lift.

C. V. Millikan,† Tulsa, Okla.—Referring to Dr. Van der Gracht's question, I think I can give an example which is pertinent. In the Wewoka field, developed a year ago last spring, the average gas-lift life of a well was about three months. That would make probably 11 of the 12 wells on the lease on the pump a year ago. I do not remember each particular well, but I believe no well there produced more oil when put on the pump than when on the gas-lift. The average production of these pumping wells today is approximately what it was at the time they were put on the pump. Many of these wells have a peculiar characteristic of fluctuating in output and many will start for a time after being put on the pump, and may soon double production. I believe this is on account of water conditions. Today we are pumping as much oil as we were a year ago from these wells.

---

* Marland Oil Co. of Texas.

† Amerada Petroleum Corpn.

As to the question of drawing in water: I have a case which is indicative of this fact. In the Tonkawa field we had two wells completed two years ago next month. These wells were about 13 months old when put on the gas-lift. They were put on the pump first and were on the pump for about four months, then put on the gas-lift. Wells on two sides were getting water.

These two wells, in the first 11 months after being put on the gas-lift, produced approximately 60 per cent. of the total production up to the time they were put on lift. At the time they were put on the gas-lift the production was doubled. One started making water three months ago and the other is not yet making water and is producing about 75 per cent. as much oil as at the time it was put on the gas-lift. If there was a tendency to draw in water because of reduction of pressure on the sand by gas-lift, it should show up in this case.

At times it is desirable to take a well off the gas-lift for other reasons. We may have a well producing 130 bbl. a day on the gas-lift; perhaps we can pump as much, but not constantly, but if we need the compressor equipment on some other well is it not advisable to sacrifice on production rather than to buy new equipment which surely will be idle in the near future?

Mr. Rubel said that tubing placed at the top of the sand was raised or lowered when the need was indicated. What does he take into consideration in determining whether to raise or lower the tubing?

A. C. Rubel.—We take into consideration the working pressure of each well, calculated, or rather reduced, as nearly as possible to working pressure at the bottom of the hole. We attempt to operate a well in such a way that we have a fairly steady working pressure. We do not attempt to maintain an absolutely smooth circle on our working-pressure chart, but we operate it so as to get what we think is best efficiency.

We have found, and I confess I don't know exactly why, that in some cases we can raise tubing 500 or 600 ft. above the top of the sand without decreasing production, and in this way we can decrease the gas-oil ratio and get better working conditions.

I must confess, as far as my operations are concerned, I am guided more by experience than formula. That is the only way I can answer your question.

Ultimate Recoveries

T. E. Swigart,* Los Angeles, Calif.—The gas-lift is only a lifting method, and except as it may influence the recovery (formation) gas-oil ratio, should have no bearing on the total ultimate oil recovery from a property, provided, of course, that operation of neighbors' wells is not such as to influence the ultimate recovery from the property in question. It is an accepted fact, of course, that the operating methods of a neighbor may greatly influence ultimate recovery in fields where wells are closely spaced. Also, in some fields with wide spacing, one well may affect another even at a great distance on account of sand conditions. Any consideration of the comparative effects of gas-lift and pumping on ultimate recovery should assume similar operations by neighbors or else should be with the assumption that neighbors' operations have no effect.

Data that have come to my attention indicate that gas-lift frequently results in slightly lower recovery gas-oil ratios than natural flowing, although there are enough examples of the reverse effect in California to nullify this as a generalization. The exact operating method, and therefore the effective back-pressure on the oil sands, decides whether or not gas-lift will lower the recovery gas-oil ratio.

Past observation has shown that pumping wells usually have lower gas-oil ratio than natural flowing or gas-lift wells, although I believe that this is a natural conse-

* Production Engineer, Shell Co. of California.

quence of prior exhaustion of gas (during the flowing stage) rather than a result of the pumping method setting up well conditions conducive to low gas-oil ratios. Therefore a conclusion that, in general, pumping wells would be expected to have greater ultimate recoveries than gas-lift wells, because their gas-oil ratios would be lower, might be entirely wrong if wells were chosen for gas-lift and pumping at the same point in their lives.

The speed of extraction of oil from wells which are suited to gas-lift flowing is doubtless greater with the gas-lift method than by the pumping method, but again, excepting the effect of neighbors' wells on ultimate recovery, I feel that recovery gas-oil ratios and not speed of extraction is the deciding factor in ultimate recovery that could be expected.

Unfortunately, very few comparative production data are available on wells that have experienced the three stages of production, and on similar and neighboring wells that have gone to pumping just after the natural flowing stage. As soon as records are available, studies can be made of comparative oil productions (including estimated future productions) and comparative gas-oil ratios of neighboring wells in the same zone during their flowing, gas-lift, and pumping stages. Total past gas productions and over-all past gas-oil ratios of wells might serve as a useful index in studying this problem. Certainly the question is one of extreme importance, but it is not one that can be decided at present with the incomplete and sketchy records available. I still feel, however, that it is a mistake to expect a lifting method to influence ultimate recovery unless that method results in a definite change in recovery gas-oil ratio and therefore recovery efficiency.

In regard to the application of gas-lift to very small wells, it is my opinion that usually they can be pumped more cheaply than they can be flowed with gas-lift, unless possibly a gas-lift compressor plant is handy and the gas lines to the small wells are already in or are not too long. The capital expenditure required to install gas-lift in very small wells is so great that unless facilities are readily available, it may be impossible to foresee operating economies that would amortize the compressor plant and lines before abandonment of the property.

The mechanical aspects of the problem of flowing small wells can be and have been overcome in many fields.

There is one advantage to gas-lift which I have not heard mentioned, and in the handling of deep wells this particular advantage may become very important. Pumping wells, particularly if they are deep and are handling reasonably large volumes of fluid—from 150 to 500 bbl. per day—require frequent pulling of rods and tubing. The handling of long strings of tubing involves a considerable risk. Also, the constant vibration of long strings of tubing caused by pumping motion and the alternate loading or unloading of fluid and by such troubles as the parting and dropping of sucker rods, increases the danger of parted tubing, and frequently parted tubing results in very costly fishing jobs or even the loss of a producing well. In the Long Beach field of California, some very disastrous fishing jobs have been experienced.

In one well the fishing occupied 11 months, and cost more than the original drilling of the well. In addition 200 bbl. a day of production was lost for 11 months, while neighbors produced offset wells at the usual rates. Eventually the dropped tubing was recovered by backing off and pulling a section of the oil string which extended below the shoe of the water string. The recovery of any appreciable part of an oil string below the water string in a California well is almost never accomplished, and in this job it would have been less surprising if the well had been lost entirely.

This hazard is something that cannot be calculated in terms of dollars and added to pumping costs, but it is a real hazard and may be so serious both in the matter of cost and possible loss of future revenue that it must be considered. With gas-lift

there is very little handling of tubing and no vibration, so this hazard is almost negligible.

Various Advantages

S. Grinsfelder,* Compton, Calif.—There may be an answer to the question of when it is advisable to take a well off gas or air-lift and put it on the pump by an evaluation of the formational gas energy. The following consideration, however, is theoretical.

It is assumed, in the case to be considered, there is no mechanical advantage of gas-lift over pump within the volumetric capacity of the pump; that is, the mechanical condition of the hole, etc., makes either method of lifting equally desirable from a lifting cost and operating basis. If this is the case, the additional expenditure for gas-lift installation over pumping equipment is justified only when this increased expenditure will return an equivalent or greater amount of value in oil.

In an attempt to clarify this point, let us consider a formational energy decline curve, this curve to represent the total energy of gas within the drainage area of a given well. This curve on coördinate paper would approximate a hyperbola, plotting pounds absolute pressure as ordinates and units of time-volume as abscissas. The work done by the expansion of formational gas would be the area under the curve.

As the drainage area of this well is depleted and the formational pressure decreases, for equal units of time-volume there would be fewer units of work done, and at some point in this curve the energy remaining in the sand would move the same volume of fluid into the hole whether the well was on gas-lift or pump. When this point is reached, the additional investment in gas-lift equipment would not be justified because the smaller investment in pumping equipment would bring the same return.

C. V. Millikan.—The cost of compressor installation in Seminole is given in Mr. Swarts' paper as some $15,000 per well. But we have some compressors now on the fourth lease, which brings the final charge per well down to a reasonable cost. I believe I am safe in the statement that in one-fifth of the wells in Seminole where the gas-lift has been used there has been a saving in deferred income alone sufficient to pay for the installation equipment.

I believe there never existed a field of any importance in which less natural energy was wasted than in Seminole. The natural gas-oil ratio is usually 600 or 700 and the rock pressure less than in most fields producing from the same depth.

It has been stated that the mechanical efficiency or flow is of small effect. I disagree with this. It is my opinion that both in natural flowing wells and gas-lift wells, if more attention is given to mechanical efficiency of the flow we will not only increase production but reduce the natural gas-oil ratio.

R. S. Knappen,† Pittsburgh, Pa.—I represent an organization that believes in the gas-lift.

Mr. Watson raised the question as to how long it would take to pump oil out of Seminole. Taking his figures of 900 wells producing 150 bbl. per day gives 48,000,000 bbl. In other words, the gas-lift has been a bunco game for the industry as a whole. We have gotten the oil out a little more quickly but consider the expense of compressors, operation of them, etc.

We had to do this ourselves because of conditions, but under ordinary operations we would have taken the oil out in two years instead of one year.

---

* Union Oil Co. of California.

† Geological Dept., Gulf Oil Co.

C. D. Watson.—I just want to point out one error in the calculation, if it is an error. You must take the number of wells completed each day at the average of 150 bbl. each progressively up to 900 wells completed to date.

R. S. Knappen.—Seminole has been in about a year and nine months.

C. D. Watson.—The first three months there were only five wells completed and on Nov. 1, 1926, there were only 40 producing wells in the entire Seminole area.

E. O. Bennett.—From results obtained on a great number of gas-lift wells, we feel that steady and uniform flow into the well is highly efficient toward keeping the porosity and permeability of the sand at a maximum. When the flow is stopped the pores tend to seal up. Steady operation is a strong argument for keeping wells on the gas-lift.

Member.—Has any observation been made on the effect on well casing where low operating pressure was used? That is, the condition of the casing in the hole in deep holes.

E. O. Bennett.—This is an interesting feature of the gas-lift work in parts of West Texas where not enough gas to circulate is available and air must be used. The air combined with sulfur water and hydrogen sulfide caused tubing-corrosion loss at the rate of five joints a day per well.

We are able, however, to produce wells by means of the gas-lift that cannot be handled otherwise and are still able to show some profit.

W. V. Vietti,* Fort Worth, Texas.—In Oklahoma they were flowing wells between the tubing and the casing. We could not do this in West Texas because of corrosion. In Oklahoma, they must pull the casing and tubing every once in a while and put in new tubing and casing. If flow is up the tubing, the casing will be saved, as the corrosion will be confined to the tubing only.

Lifting Costs

E. H. Griswold.—In the discussion on cost, there seemed to be some doubt as to whether the ultimate lifting cost per barrel by gas-lift was going to be less than by ordinary pumping methods. I know of leases in Oklahoma where gas-lift is used to produce wells making from 50 to 250 bbl. per day each with a lifting cost of less than 25c. per bbl., allowing a depreciation of 25 per cent. on compressor installations. The life of the compressors should easily be more than double that allowed by this fast rate of book depreciation.

One air-lift well in Kansas is producing 3500 bbl. of water per day with only 135 bbl. of oil. Corrosion is so severe that the tubing is replaced every 60 days and the $5\frac{3}{16}$-in. casing has been replaced twice within the last 10 months. It is necessary to produce this well in order to protect the surrounding pumping wells; but in spite of the corrosion troubles, the air-lift well is paying its own lifting cost and showing some profit.

A. C. Rubel.—I believe I can give some explanation as to why the lifting cost varies so much. I don't believe any two companies in the United States have the same accounting methods. When you talk about "lifting cost" you are comparing individual accounting methods. I know the A. P. I. Standardization Committee contemplates standardization of oil-field accounting, and perhaps then we can talk about "lifting cost" on some standard basis.

We are trying to introduce a system whereby lifting cost will be divided into actual lifting cost and production cost, taking in what is now generally known as, and called, lifting cost. Until then we had better not try to compare lifting costs.

---

* Production Engineer, Marland Oil Co. of Texas.

H. P. Porter.—This question of cost brings up the problem of cost accounts of oil companies. Anyone who has had reason to keep account of operations in an oil company and to gather information from the accounting department, has no doubt found that the information obtained is worth nothing. Is there any plan or proposal the engineers might make that would bring about a cost-accounting system that could be a standard method, to be recommended to the oil companies, whereby we would be better able to get information from oil company accounting departments? I think this should be studied and planned by the engineers and submitted to the A. P. I. committee on methods of accounting.

E. O. Bennett.—That is being done in some companies. I believe this is out of the realm of our meetings in general and is coming up under the A. P. I. However, there is no reason why the engineers interested should not work on this and submit their ideas. I do not know of any two companies today who can compare lifting costs on a proper basis. Each one has certain ways of setting up depletions, drilling costs, etc., and the way in which these are handled will make statements look different.

W. V. Vietti.—As purposes for keeping costs are so diverse it seems to me it would be best to have the listing cost statement itemized, showing the various items that make up the charge.

H. P. Porter.—In any ordinary engineering investigation in any other industry the engineer gets all the facts and information, makes a complete survey, estimates cost of operation, interest on investment, and all items going to make up the operation. That is, he figures out the gross revenue, etc. and when he is through he can compare everything, and see where he made a profit or loss. Cost accounting for the benefit of the engineering and management departments of oil companies is what is needed.

A. C. Rubel.—These are facts that we should try to bring up in our A. I. M. E. papers, and individually we should bring as much influence to bear as possible on our own companies to show that we need this information. We have a hard time getting it in many cases. The comptrollers' departments do not know that we need the facts, but as soon as they understand our needs we will get the results we want.

H. N. Johnson,* Los Angeles, Calif.—I believe we will all agree that this series of papers has demonstrated that the development of the technique of the air-gas lift, and its application to the production of oil, has been nothing short of an engineering triumph. By its use we have been able not only to produce more oil in less time and probably at less cost than by ordinary pumping methods, but also, as Mr. Bennett pointed out, to increase the ultimate production of some wells up to 100 per cent.

Last evening Mr. Pogue called our attention to the reverse side of this question: that this recent development of technique has cost the industry as a whole a loss of not less than five hundred million dollars during the current twelve months.

Granting that the economic problem is one resting on the executives and not the engineers as such, it seems to me that there might properly be given figures, or at least an expression of opinion on the part of the engineers making these field investigations, as to what extent the gas-lift has been responsible for this great loss to the industry.

Has anyone any figures that would give an idea as to how much oil has been produced by the gas-lift during the past four or five years as compared to the amount that would have been produced by the use of ordinary pumping methods alone; *i. e.*, what percentage of our oil in storage today and our current production, particularly

---

* Geologist, General Petroleum Corpn.

at Seminole, is chargeable solely to the air-gas lift. Could the industry otherwise have withstood the coming in of recent flush fields without this great collapse in price?

I think that most of us are apt to consider that the evil effects of the air-gas lift rests solely upon the operators in the older fields where this process could not be used. But even at Seminole, has the increased amount of oil brought to the surface by the air-lift compensated the local operators for its cost and the resulting collapse in price per barrel? This, of course, involves the question of what effect on price would have resulted from this flush field even under normal production methods.

Information that would aid us in determining to what extent the use of the air-gas lift is responsible for our present dilemma would be interesting. I realize that this point has not been brought up thus far in our technical sessions, which are the only ones officially reported, and it seems to me that there is, therefore, danger of the impression going out to the public in general; either that we are ignorant of the larger issues before the industry, or else are opposed to the wishes of those among us who are endeavoring to conserve the oil in the ground.

My question is, has anyone any estimate as to the amount of this excess oil produced by the air-gas lift and the effect of this excess alone on the industry?

E. O. Bennett.—I have not made any estimates. I do not think the gas-lift has been responsible at all but the means of application of it have been. It is a tool—when properly used it is a good tool. It is the production engineer's duty to devise the most economical means of obtaining production and the executive's duty to prescribe the rate at which production should be maintained.

F. E. Wood,* Casper, Wyo.—I had the good fortune to attend the recent meeting of the Conservation Committee of the A. P. I. at Ponca City. It is a little difficult for me to harmonize the general impressions left at that meeting and the impression the public might get of this meeting. There it was said: "Let us keep this oil in the ground —conserve it." While this is a meeting more for the purpose of developing technique of practice, it seems to me the public might get the impression that the engineers are advocating a practice that might ruin the industry.

There is one phase of the gas-lift which I believe this meeting has neglected: that is, the economic side, or the dollars and cents value of gas-lift installation. Let us take an average case: gas-lift installations cost from $15,000 to $20,000 per well according to information developed in this meeting. To break even on this expenditure in a field with 10,000 bbl. per acre as expected ultimate yield without gas-lift and wells spaced one to ten acres, it is necessary for the gas-lift process to increase ultimate recovery from 20 to 30 per cent. over what might be expected with normal production methods. To make a profit and properly justify the investment it would be necessary for the increase in ultimate recovery to be in excess of 20 to 30 per cent. This is a hazardous risk for any company to take, as we have no definite information to what degree the gas-lift increases ultimate recovery, if at all.

J. B. Umpleby,† Oklahoma City, Okla.—I also attended the meeting at Ponca City and see a clear difference between the two meetings. I believe that such a difference is desirable. At Ponca City several of us were placed on the witness stand in order to determine those fundamental points on which we agreed. In this meeting we are trying to arrive at more points of agreement. I am impressed that we are in the effort of fact finding, they are in the effort of fact using. Otherwise expressed, we are an organization trying to advance technique; they are an organization trying to determine how to apply available technique to the best service of the industry.

The same thought was brought out last night by Dr. Pogue in his talk at the smoker. He stated facetiously that the outstanding event of 1927 was "The Seminole

---

* Petroleum Engineer, Midwest Refining Co.

† President, Goldelline Oil Corpn.

Follies," but added that technique had progressed ahead of economic control within the industry.

I quite agree that as engineers we should be alive to economic consequences when we make recommendations and at times should place emphasis on them, but our outstanding problem is to get the most oil out of a given acre of sand at the lowest cost per barrel. Whether or not to apply a particular method at a particular time is primarily an administrative problem. I see a very clear distinction between our effort to advance knowledge and the effort of the Ponca City session to determine the proper use of the knowledge available.

W. van der Gracht.—We should certainly not let the idea gain headway here that there is any conflict of purpose between this meeting and the one we had in Ponac City. It is certainly not true that progress in petroleum technique is necessarily in conflict with conservation.

We have no proper conception of conservation if we believe that its object is merely to produce less oil, and thereby to increase the market price for it. That is not the idea at all. Mr. Marland emphasized that in Ponca City.

Under present conditions of competition oil is produced very inefficiently. The cost is unnecessarily high, because often far more wells are drilled than are required to economically drain the deposit. Less oil is taken out of the ground ultimately; through undue haste, waste of gas pressure or drawing in of encroaching water, much oil is made unrecoverable, is left behind in the sand, which would otherwise have been produced. This procedure unbalances the market periodically; neither does the producer know what profits he will make, nor the consumer what price he will have to pay six months from now. Periods of hardship for producer and for consumer alternate constantly; that is not in the interest of either, and in addition it wastes the nation's resources.

Every engineer knows that, if present conditions did not exist, we could produce ultimately much more oil, and that we could produce it more cheaply, meaning that the consumer would be assured of a more stable supply at a low price, and yet the producer be certain of a reasonable profit. Each side is entitled to that. The nation as a whole has a right to its resources; that no oil be left in the ground that could be economically produced.

This is all there is to conservation. It is not to reduce production and to raise price, but to produce more oil at so much less cost, that the petroleum products can be sold cheap and yet yield such a reasonable profit to the producer that steady production is maintained.

If conditions can be created which will allow us engineers to apply what we know, but what circumstances do not permit us to use now, we will have all the conservation we want. It will then stimulate us to further improve our methods, and to reduce costs even more, meaning cheaper oil. Competition of the right kind will accomplish that; the present kind of competition can only cause periodic disaster, hardships alternately to producers, to investors and to consumers, and cause premature exhaustion of the nation's resources—meaning shortage, expensive oils and ultimately inferior substitutes at a higher cost. We can defer this until possibly we have good substitutes at a low cost, and yet continue to produce more oil and sell it cheaper. There is at least four times more oil in our pools than we take out now. We want to make a considerable part of that oil, which is now wasted, available to the market, at no higher price. That is the conservation we talk of.

J. M. Lovejoy, Tulsa, Okla.—It seems to me that our only problem as engineers is to produce as much oil as we can from a given oil sand at the lowest possible cost. This is an economic problem within the industry, economic because costs are involved, but should be clearly separated in our minds from the economics of the industry.

---

* Vice President, Amerada Petroleum Corpn.

If the mining engineers in the copper industry could evolve cheaper methods of mining copper, there is no question that they would immediately be put to use.

The economics of the gas-lift is twofold. On one side the problem is as stated above, whether we can produce more oil at a lower cost with the gas-lift or not. The other broad economic question involving the gas-lift is whether or not the increase of production due to its use has been of benefit to the industry.

Assuming that the gas-lift has proved itself as an engineering method, the use of it lies to a great extent with the executives of the oil companies rather than with the engineers themselves. I have attended a great many "shutdown" meetings this year. The Seminole operators have met once or twice a week for a period of four or five months. The matter of the gas-lift, which was supposed to have ruined the oil industry, was brought up time and again. At several meetings certain operators put up to the meeting whether or not the gas-lift should be removed from the entire Seminole field. This suggestion never received very general support, but I wish to add that right there the executives had the power to prevent the use of the gas-lift and they should have done so if they were in agreement that this method of producing oil was uneconomic from a broad viewpoint.

To repeat myself once more, I believe the problem of the engineer strictly is one of recovering the greatest amount of oil from a given sand at the lowest cost.

A. W. Peake.—Dr. Umpleby said this meeting was a fact-finding meeting and that the one at Ponca City was a fact-using meeting. Mr. Lovejoy said this body was not interested as engineers in the economic aspect of the situation.

I think it should be interested in this. I think if we are not, we should get on that problem as soon as possible.

The executives of companies are guided, to a great extent, by the recommendations of the engineers, and when engineers become so overenthused as to the possibility of their stampeding their executives in something which is wrong in its economic aspects they are at fault.

There always has been that criticism of engineers—that they are only interested in the technical side, regardless of the cost.

I think this Petroleum Division of the A. I. M. E. should not take the stand that we are only a fact-finding and not a fact-using body, but we should get on the economic side at the same time.

Earlier in the discussion I asked a question regarding the formation gas-oil ratios on gas-lift as compared to that in flowing and in the pumping part of the life of a well. I think it has been stated that the gas-oil ratio can be decreased by use of the gas-lift. A few representative cases, as they call them, have been cited, supporting this contention, but can anyone submit data from a large number of wells, which will show the balanced average to be one way or the other?

G. C. Gester,* San Francisco, Calif.—I am not in a very good position to talk upon the matter you have had under discussion as I have just arrived here and have heard only a little of what has been said.

As you probably all know, the meeting at Ponca City was for the purpose of finding out what is actually known in the petroleum industry regarding the value of gas in the production of oil. It was, therefore, in that sense, a fact-finding meeting, the record of which it was hoped might serve as a guide to the executives and directors of the A. P. I. on which they might base their actions regarding oil-gas conservation matters.

In only a small particular do I think that the meeting in Ponca City differ from this meeting. Possibly a wider range of subjects is being discussed here. This

* Chief Geologist, Standard Oil Co. of California.

meeting, like most technical or scientific meetings, I would judge, is also here to find facts, as well as to discuss theories, and I would judge from the little I have heard that you have many problems relating to gas-oil ratios, gas-lift, production methods, etc., which have attracted your interest.

Primarily, what is the object of your discussions—discussing new data, finding out what are facts? If so, I do not see a great difference between this and the Ponca City meeting. They are both for more or less the same object.

You may be assured that the facts developed here will be wanted by the scientists, by your executives, and by the oil industry at large.

One statement was brought up a few moments ago; namely, that the principal object of the petroleum engineer was to develop methods by which oil might be extracted more economically. I think that it is also his problem to develop methods that will promote a greater recovery of oil and a better understanding of the value of gas in the recovery of oil.

R. S. KNAPPEN.—As I understand it, an engineer is one who knows the value of the dollar. It was not a question as to whether the A. I. M. E. should condemn the gas-lift *in toto*—the question was, "Has it justified itself?" Figures were shown on the cost of installation of gas-lift but there are other costs such as depreciation of equipment, corroded casing and tubing, compressor operation, etc. Now, unless we can show that the gas-lift improves ultimate recovery, it is a loss to the industry. I do not think Mr. Wood had in mind prohibitive cost, but does the gas-lift sufficiently improve recovery to justify itself? I confess I have not enough evidence to believe the gas-lift has justified itself in improved recovery. It has given smooth operation and rapid production, but has it improved ultimate recovery sufficiently to justify the increased cost?

A. C. RUBEL.—It seems that in the minds of some of us we stand charged with a serious offense. I think this matter is of sufficient importance to get a cross-section of our opinions. I would ask Mr Harmon, as a practical operator and executive, for his reaction on this question.

I. G. HARMON,* Fort Worth, Texas.—It seems that in these discussions we are inclined to obscure fundamentals with what I believé are details. The fundamental problem of the gas-lift, to my way of thinking, is a mathematical problem. We know some of the facts, some we do not know. In some wells we are able to get a definite answer. Where we fail it is because we either do not know some of the facts or because we are poor mathematicians. As time goes on we will be able to solve most of these problems.

In the discussion last night and this morning the overproduction in the Seminole area was, in some manner, blamed on gas-lift operations. It seems to me that this is confusing an economic problem with a purely engineering problem. From a purely engineering point, it makes no difference whether oil is worth $1 or $2 per bbl. The problem of engineers is to produce all of the oil possible for the least amount of money possible. If we produce more oil than the market can absorb, it is an economic problem and not an engineering problem. If, through executive control, or any other channel, the engineer is caused to deviate from this line, I think he is untrue to both himself and the public.

F. E. WOOD.—Mr. Knappen has brought out the point that I am not condemning the gas-lift. This is exactly the case. I think the gas-lift is a method of operation which has been developed to a high degree of efficiency and is a credit to the engineer. Gas-lift has its application in fields where the ultimate recovery is high and the percentage of additional production to justify the installation is not as important as in

* Marland Oil Co. of Texas.

the average case. Gas-lift may also be justified where deep production is encountered or where wells sand up readily. The point I have in mind is: let us not as engineers recommend investments of $15,000 to $20,000 when the prospective profit is considerably less than this amount. To clarify further my former remarks, it is often stated that gas-lift has an advantage in that it produces the oil more quickly and thereby returns the investment at an earlier date. This premise is correct up to the point where the oil is produced so rapidly that there is an over-supply which is attended by a drop in the price of crude. In addition to the increased amount of crude necessary to justify gas-lift installations, it is necessary to consider the loss from drop in the price of crude. In January, 1927, the average price of Seminole crude approximated $2 per bbl. At the present time it is approximately $1.30 per bbl. This drop can be attributed largely to the efficiency of gas-lift in producing oil more rapidly than it could have been produced by any other production method. Therefore, from an economic standpoint, the gas-lift in this field will show a loss or will have to produce a tremendously large volume of oil in excess of what could have been produced under normal operation in order to offset the drop in price of crude which is largely credited to its account.

New Developments in Air-gas Lift Operations in the Mid-Continent Area

By C. V. Millikan,* Tulsa, Okla.

(New York Meeting, February, 1928)

New developments in air-gas lift practices in the Mid-Continent area since our Fall meeting in Fort Worth have done much to increase the efficiency of installations, and thus bring within economic limit of air-gas lift many wells which could not have been flowed profitably before. After the gas-lift had so thoroughly demonstrated its value in the Seminole field, its use spread to other areas and many installations were made of which the economy could be questioned. In the Seminole area, when production began to decline it was necessary either to increase the efficiency of the air or gas-lift or to put the wells on the pump, and pumping was not a process of lifting oil to which any operator looked forward with confidence. These conditions have resulted in the development of many practices which increase the efficiency and permit wells to be flowed with air or gas which earlier could not have been flowed economically, and wells which have been flowing to continue to a lower rate of production. The practices which have come into more common usage in the Mid-Continent area recently are mostly revivals of and improvements on practices which have been known in air-lift work for several years. Many are peculiar to the individual well on which they are used.

Intermittent Flowing

Some interesting results are being obtained in Seminole and other districts by intermittent injection of gas. Gas is introduced during periods of 3 to 5 min. at a rate considerably over that necessary to acquire the production at a steady rate of injection, and is then cut off for a period of 3 to 15 min. Two to five wells are run from the same group of compressors. The total volume of gas required is sometimes reduced as much as one-third of that required when it is introduced at a constant rate, without changing the amount of oil production. The maximum pressure required is usually higher, but the average equal to or lower than that required for constant rate of flow. The effect on the wells is usually an irregular rate of flowing which may cause inconvenience where recycling is practiced. It would seem that this increase in efficiency is due to less slippage when the gas is introduced intermittently than when it is intro-

* Amerada Petroleum Corpn.

duced steadily, and is rather opposite to the more commonly held theory that the smaller the bubbles of gas when introduced into the column of fluid, the greater the efficiency of the lift.

Intermittent flowing is a method of air or gas-lift which has been practiced in some of the shallow fields for many years but is not yet established as a common practice in newer and deeper production. Some small wells have been flowed three to six times a day and the same production obtained as when they were flowed continuously. It has been used on wells making considerably more fluid, but the practice is not common. Flowing intermittently where recycling is practiced throws an overload on the compressors at each head with an underload between heads, and this is turn causes an uneven volume to be delivered to all wells being flowed from the compressor plant. Were it not for this uneven load, intermittent flowing would probably be used more extensively than it is at the present time, especially on wells making only a few hundred barrels of fluid.

Three methods of intermittent flowing are used: (1) with tubing arrangement, as for continuous flowing; with the tubing set on a packer with perforations above the packer and valve below the perforations; (3) by running two strings of tubing, the larger size being ordinarily 2½ in. or 3 in. with a valve on the bottom and a smaller size inside. A few joints of larger size are sometimes run on the bottom of the outer string for a volume chamber.

The latter two methods have the advantage of keeping high pressures off the sand, although this is not often detrimental except when the pressure is held long enough to force the oil back into the sand instead of up the tubing. When more dependable kick-off valves are available, intermittent flowing will be in more common use.

Holding Pressure on Gas Trap

Holding pressure on the gas trap is becoming a more general practice, especially where the gas is recycled. Most compressors are driven with an engine or motor of sufficient power to run the compressor with atmosphere intake pressure and a discharge pressure much higher than the working pressure of the particular well being flowed. By holding a pressure on the gas trap the gas can be delivered to the compressors at a pressure above atmospheric, and the surplus power utilized by the larger volume delivered. Trap pressure up to 10 lb. does not often affect the production and frequently a much higher pressure can be held. In the deeper wells there is seldom any effect on the working pressure, but in shallow wells it is usually changed the same amount as the pressure held on the trap, even for 3 to 5 lb. Even where the flowing pressure is increased when pressure is held on the trap, the small additional power cost may be more than saved by reduction in amount of equipment

required, due to the increase in volume delivered by the compressors already installed.

Volume Controllers

The use of instruments for automatically controlling the volume of air delivered to a well has been considerably abused and as a consequence they are not as popular as they were a few months ago. In a plant which is equipped with a volume controller on each well there is a tendency to use all the controllers, even though a majority of the wells require much less pressure than others. Such a practice not only requires more power but reduces efficiency of the compressor and increases wear on equipment. The instruments are valuable when used only on wells with approximately the same working pressure, as their use will often allow part of the machinery to be shut down, and then when it is necessary to shut down a compressor for a short time the decrease in volume to any one well may not be so great as to cause it to stop flowing. If conditions should arise making it desirable to flow two wells with different working pressures from the same group of compressors, the volume can be satisfactorily controlled by partially opening a gate or needle valve between their pressure lines. This method has the advantage that the compressor connected direct to the well with the lower pressure does not have to work against the same pressure as that required by the higher pressure well, which is necessary if an automatic control is used. If recycling is practiced and the intake pressure to the compressors very irregular, a needle valve will not give the perfect control obtained by an automatic controller, but does not often vary sufficiently to affect the oil production.

Tubing Sizes

Graduated tubing is becoming more commonly used throughout the Mid-Continent area. Some companies are using it almost exclusively, except for wells with very large potential production. Straight strings of tubing are still used to a limited extent, but in nearly all cases where wells flowing through straight tubing have been changed to graduated tubing, a material reduction has been obtained in both the pressure and volume required. There is not often any change in production that can be attributed to changing to graduated tubing. Many companies are still flowing through the annular space between the tubing and casing, even for the smaller wells. While such a practice may require a larger volume than flowing through tubing, the pressure is usually lower and the ultimate lifting cost essentially the same, except on wells with small production. Most compressor equipment throughout the fields is designed for much higher pressures than are ordinarily required, and therefore if the volume can be reduced by flowing through tubing, a saving in equipment usually results, even though the efficiency is not

changed. Flowing through tubing invariably imposes greater pressure against the sand than flowing through the annular space between the tubing and casing. When flowing through the tubing the friction loss of forcing the gas down through the annular space between the tubing and casing is negligible, and the pressure shown at the casinghead is, for all practical purposes, the pressure at the bottom of the tubing. Where gas is forced down the tubing there is a material friction loss which on a large volume may amount to over 100 lb. It is sometimes desirable, however, to maintain this higher pressure on the sand to reduce the natural gas. This is practiced in connection with gas-lift work in the Panhandle, parts of West Texas, and to a lesser extent in other areas.

Determination of the size of tubing which shall be used in a well, and where graduated strings are used, the amount of each size to be run, are as yet individual problems. They are calculated or estimated in as many different ways as there are different engineers to calculate them. There are, however, certain principles upon which the calculation should be based, and engineers are in general accord on these. More detailed data are being obtained and better understanding of the action taking place in each installation, so that more and more installations are made on an engineering basis rather than by comparison with similar wells.

Working Pressures

One company in the Seminole field is making a practice of flowing up through casing run for this purpose, which permits cleaning out, swabbing or other work to be done on the well without interruption of production. The pressure necessary to hold against the sand is reduced because of less flowing friction through the large pipe, but the casinghead working pressure may be high because of greater friction loss in forcing the gas through the small area between the two strings of casing to the point of injection into the oil column. Another disadvantage is that the point of injection of gas into the oil column cannot be changed. Where tubing is used, it can be lowered as far as necessary to obtain maximum production, which is sometimes several hundred feet above the sand. Placing the tubing below this point will increase the working pressure without increasing the production, and also frequently increases the natural gas-oil ratio.

Some further work has been done on the use of large flow strings for air-gas lift work[1] and has given some encouraging results. While the volume required is much greater than the more common sizes of flow strings, the pressure can be reduced low enough to use single-stage compression. The volume of natural gas is usually materially reduced, but this may not result when used during the earlier life of a well. One installation in northern Oklahoma is now lifting 400 bbl. from 3000 ft. with a working pressure of 45 pounds.

[1] E. V. Foran: Mechanical Installations of Gas-lift. See page 59.

Automatic kick-off valves to reduce the starting pressure are available in several designs, most of them depending on a differential pressure between the inside and outside of the tubing for the operation of the valve. One design is operated by means of a wire from the valve to the surface and another by the velocity of the gas through an opening. There are several of these valves in use in the Garber, Okla., field and the Gulf Coast fields, but their general use is not common. In most areas the equipment is capable of withstanding the starting pressures required, and therefore there is no particular demand for these valves. Some trouble has occasionally been caused by running one of these and having it fail to operate properly, and one failure on a well of big potential production will make any operator hesitate to try again any piece of equipment for that purpose. While the use of automatic kick-off valves at the present time is not common, improved designs may be expected which will bring them into more general use, particularly where high starting pressures are required.

Stage Gas-lifts

Recent experiments have been conducted in lifting oil by means of a series of gas-lifts within the well, the principle of which is identical with the stage lift which has been frequently applied to lift water from deep mines. The design for oil-well pumping requires three strings of smaller pipe run inside of a larger size. At regular intervals a special coupling is installed, each of which is the beginning of another stage of the lift. Two of the small pipes are eduction pipes and the third a vent pipe for venting the gas spent in lifting the oil through the lower stages. In the operation, gas is introduced through the first coupling into one of the lift pipes, to raise the oil through the second coupling to the bottom of the third coupling where it is discharged, the oil falling back to the second coupling and the gas going up the vent pipe. More gas is introduced through the second coupling to lift the oil through the other lift pipe, through the third coupling to the bottom of the fourth coupling where it drops back to the third to be picked up again, the gas going into the vent pipe. This process is repeated until the oil reaches the surface, all of the stages working simultaneously.

The stage lift may be operated by the gas produced with the oil by holding sufficient pressure on the casing to operate the lift, or may be supplied by a compressor. The pressure required depends on the distance between the couplings. This is usually about 35 lb. when the couplings are placed some 65 ft. apart, and proportionally greater for longer lifts. There is little to be gained by placing the couplings closer, as the additional volume of gas which must be vented imposes a higher pressure on the lower part of the vent pipe, which in turn requires a higher pressure to be maintained in the casing to operate the lift. In

case extraneous gas from a compressor is to be used, the gas is introduced through one of the smaller pipes and the spent gas vented through the annular space between the tubing and casing. The volume of gas entering each stage of the lift is controlled by an orifice. Because of the small size of the pipes and numerous aerations in the process of the lift, paraffin is more troublesome than in other methods of pumping. On the whole, it is promising as an economic method of lifting where conditions are favorable for its operation.

Study of Special Problems

Sentiment in favor of compressor plants for gas-lift, gasoline extraction, repressuring, and gas-line boosting is gathering force, and the near future will probably bring a different operating policy for some of the present plants and new plants which will be built.

Most operators who are now lifting oil by means of air or gas-lift are studying their individual operations closely, not only that the individual wells may be operated as cheaply as possible, but also to obtain data which will assist in establishing general principles governing the lifting of oil by this means. One of the most promising fields for the application of gas-lift principles is in wells flowing naturally. Little has been done toward designing the size and arrangement of tubing in order to prolong the time that a well will flow by means of its own natural forces. The most common practice in the Mid-Continent area is to complete the wells with 6⅝ or 5-$\frac{3}{16}$ in. casing for the oil string. The well is permitted to flow through this as long as it will, then tubing is run either to obtain further natural flowing or for flowing with compressed air or gas. In many wells if the flow string were designed as carefully as tubing in an air or gas-lift installation, natural flowing life could be materially prolonged and lifting cost reduced.

The present tendency is toward operating wells with smaller production by means of air or gas-lift. While for constant operation of pumping that method is more economical than most gas-lift operations lifting the same amount of oil, the loss in production due to shutdown time and extra labor incident to frequent pulling of rods and tubing put the air-gas lift in strong competition with pumping in many wells because of its consistent operation. Improved methods of air-gas lift which are being made and will be made will bring this method in even stronger competition with plunger pumps, especially in the deeper wells. And the present trend of oil-field development is decidedly toward deeper wells.

DISCUSSION

H. P. Porter,* Tulsa, Okla.—This paper states, in paragraph 2, referring to the intermittent method of lifting, that the effect is rather opposite to the theory that the

* Gypy Oil Co.

finer bubbles are desirable in a lift to secure the greatest efficiency. Another way to describe the action in this paragraph is: The fluid settles into the form of a piston during the off period and then the gas being admitted behind it drives it upward with less slippage.

Well No. 3, in Section 13, Township 8, Range 6, Oklahoma, had been pumping and was changed to an intermittent flowing method. This well, pumping on the beam made 75 bbl. per day, and with the intermittent flowing method it produced 120 bbl. per day.

Reference is made to two methods using double strings of tubing and check valve to keep the pressure off the sand. All experiments observed by the writer in the greater Seminole district, where the wells are 4000 to 4500 ft. deep, have proved this method to be unsatisfactory. A deep well has so much volume of tubing to fill between flows with high-pressure gas, that this probably contributes to the failure of the method; also, due to the two strings of tubing, there is a greatly decreased hydraulic radius, causing friction, which in turn makes it necessary to create a high gas pressure.

Many operators have an impression that it is possible to keep pressure off the sand with a check valve and packer. It might be possible to do some good with such a device in case of intermittent flowing, but when flow is steady, it has little value, and is more than likely detrimental.

Mr. Millikan says: "Holding pressure on the trap is becoming more general practice." This is true with many producers at present, but in every case where there is low rock pressure upon the sand, be it due either to low pressure or lack of hydrostatic pressure, the effect is to increase the amount of oil produced. Consequently, better practice is now being recognized by engineers who use vacuum or booster units to draw the gas away from the traps and deliver it into the suction of the high-pressure units at a pressure of 5 to 15 lb. gage. This greatly increases the capacity of the high-pressure units and permits better control of the flow pressures at the well head and trap.

On the whole, Mr. Millikan has covered the subject of the air-gas lift very completely and the points brought out relative to probable trend of design in equipment and practices in operation are well worth the consideration of our production engineers.

C. E. Beecher,* Bartlesville, Okla.—Mr. Millikan made a statement to the effect that the pressure at the top of a well is approximately the same as that at the bottom when putting the gas into the well between the tubing and casing for the purpose of flowing up the tubing. There is a small difference in pressure due to the weight of the gas which, as a rule, can be neglected. However, when flowing through tapered strings of tubing under comparatively low pressures and small volumes it may be desirable to consider this difference in pressure for computing the velocity of flow in the tapered tubing. The area of the annular space between the tubing and casing is usually so large that little pressure is lost in friction between the top and bottom of the well. For a well 4000 ft. deep with a working pressure of 100 lb. gage at the casinghead, and assuming a gravity of 1 for the gas and no friction loss, the pressure at the bottom would be approximately 115 lb. gage and the volume reduced about 11 per cent.

J. B. Umpleby,† Oklahoma City, Okla.—It seems that air-gas lift has reached a stage where there are two principal objectives—first, to reduce the cost of installation, and second, to make it applicable to smaller wells. Many deep wells are so crooked that to install pumping equipment late in their lives when the production is small is

* Production Engineer, Empire Gas & Fuel Co

† President, Goldelline Oil Corpn.

almost prohibitive. The problem is up to the engineers whether they cannot design the air-gas lift in such a way that it can be carried to the last stage of production on such wells. Mr. Millikan, in the case of intermittent flowing, what is the volume of gas per barrel of oil?

C. V. Millikan.—In intermittent lifting on one well flowed four times a day we used one compressor which would deliver at the rate of about 300,000 cu. ft. per day. The compressor was run about 30 min. each time the well was flowed, which for a daily production of 100 bbl. would give a gas-oil ratio of about 400.

J. B. Umpleby.—Do you completely exhaust the compressed air from the well between flows?

C. V. Millikan.—We allow it to drain off. In other words, we just break the well out four times a day.

J. B. Umpleby.—Do you not then put in something like 8000 or 9000 cu. ft. in order to fill the casing before the lift starts?

C. V. Millikan.—Yes, that is all discharged.

J. B. Umpleby.—It would seem desirable to find some way to avoid that waste of energy. I wonder why we could not place a check valve and packer at the bottom of the casing and only discharge the gas in the tubing between flows. In this way a charge of gas at somewhat reduced pressure might be held between the tubing and the casing between flows. I do not know what the saving in compressor work would amount to but suspect that it would approach 50 per cent. on old wells.

C. V. Millikan.—That waste may also be reduced by using a smaller line from the compressor to the well and smaller tubing for the gas, thus reducing the volume between the compressor and the bottom of the tubing which it is necessary to fill with gas at high pressure. This would probably be more of a gas-displacement pump than a gas-lift.

J. E. Pogue,* New York, N. Y.—Probably the two most brilliant engineering developments in the petroleum industry in recent years are the gas-air lift and cracking. The gasoline content of the crude oil produced at Seminole in 1927 by the gas-air lift is almost equivalent to the cracked gasoline which could have been produced in 1927 by the idle cracking capacity, but which was not produced because of the low prices brought about in part by the overproduction resulting from the use of the gas-air lift.

---

* Consulting Engineer.

Recent Developments in Gas-lift Methods in California Oil Fields

By A. H. Bell,* Los Angeles, Calif.

(New York Meeting, February, 1928)

The general principles of the gas-lift will not be described in this paper. Only specific details that have not been fully discussed in previous papers, or results that do not fully coincide with conditions previously described, will be dealt with. The principal points to be emphasized and for which supporting data are furnished are as follows:

1. Gas-lift installations usually have comparatively high efficiencies as compared with standard pumping equipment, when reduced to a basis of barrels produced per horsepower installed.

2. Advantages of high-pressure plants from the standpoint of operating efficiency and for the application of the gas-lift early in the life of flowing wells.

3. Evidence of increased ultimate yield through conservation of gas by the gas-lift.

4. Possibility of development of new equipment to increase efficiency of the gas-lift.

5. Indications of the advantages of repressuring as a means of stabilizing gas-lift wells and as a means of increasing ultimate yields.

Types of Installation

The gas-lift installations of the more important companies in California have been of the central-plant type wherever field conditions would permit. This has resulted in greater flexibility and lower installation costs per well than could be obtained with individual well units. In general discussions of the gas-lift method of production, the installation costs are frequently referred to as being too high for economical operation. If the field conditions are carefully analyzed and the plant designed with the idea of obtaining high operating efficiencies, the installation cost per well can be lowered sufficiently to compare favorably with individual well-pumping units, when the operating advantages are considered. Much greater production per horsepower can be obtained with the gas-lift than is possible with pumping equipment.

Table 1 shows the unit sizes and costs of gas-lift installations of three companies in the Los Angeles basin. The cost of walking beams, rods,

* Chief Production Engineer, Marland Oil Co. of California.

pumps, electric-power lines, etc., have been omitted, as they are balanced by the cost of gas lines to the wells, and such items are variable.

TABLE 1.—*Data on Three Gas-lift Installations*

Plant	Average Casing Pressure, Lb.	Average Submergence, Ft.	Average Tubing Depth, Ft.	Horsepower Per Well	Daily Barrels Per Horsepower	Installation Cost Per Well
A	450	1,650	2,900	85	71	$11,000
B	178	1,900	3,900	39	39	6,100
C	210		4,000	46	3.2*	6,600
Gas-engine pump				40	11	3,600
Electric-motor pump				30	15	3,000

* This is an old installation and the wells have declined to a low figure; also, the production is beaned back.

A survey of the amount of gas theoretically required to lift a barrel of oil under different conditions of submergence as compared with the capacity of a compressor engine at the different pressures required will determine the most economical pressure and submergence from the standpoint of installation and operating cost. However, a casual investigation seems to indicate that greater percentages of efficiency are obtained with the high-pressure lifts using smaller tubing and greater submergences, so that the actual pressure for best results is slightly greater than indicated by purely theoretical requirements.

In a comparison of several wells in which all conditions are nearly equal except submergences, the gas-oil ratios show a decrease of 25 to 50 per cent. with a change in operating pressure from 300 to 450 pounds.

There is very little that has not already been said about the method of equipping wells for the gas-lift. The practices of setting the traps above the derrick floor, eliminating right-angle bends and horizontal lines, etc., have been adopted by the various operators, each layout having its merits. There are practically no wells being flowed between the casing and tubing, as most operators believe that this method is not conducive to good results. Natural gas, usually treated, is used in all California gas-lift plants.

Operating Results with Gas-lift

The results to date obtained from the principal gas-lift installations have been in favor of the gas-lift over pumping with rods. Unfortunately, however, operating costs are not available for publication.

Disadvantages

The only serious disadvantages of the gas-lift which are found to be general are as follows:

Emulsions.—Due to the agitation of the fluid, wet wells produce an emulsion which is very viscous and difficult to dehydrate. There have been several cases of emulsions so viscous that they would not flow from the gas traps, so that the wells had to be taken off the gas-lift and put "on the beam."

Gas Supply.—After the fields have passed the flush stage there is usually a shortage of gas due to lease fuel requirements and the shrinkage in gasoline-plant operations. The chief disadvantage of the use of air or flue gases is the loss of gasoline-plant revenue, which is an important item in most California fields.

Back-pressure on Low-head Wells.—With wells in which the fluid level is very low the effect of the gas pressure on the fluid is to retard production. This can only be overcome by using larger tubing and excessive gas circulation which results in costs out of proportion to the production of the well.

Advantages

The most striking advantages of the gas-lift are:

Elimination of Rod Troubles on Deep Pumping Wells.—Deep pumping wells have many shutdown periods due to parted rods, sanded pumps, etc. Also the wear on tubing is often excessive on account of crooked holes. With the gas-lift there are no moving parts at the well to require operating attention or cause wear or breakage. The compressors when grouped in one plant have the constant attention of a skilled operator, which should result in longer life of the machinery. Figures are not available to determine the average life of a pumping gas engine as compared with the larger compressor engines, but such an investigation would be enlightening.

Increased Daily Production.—Numerous data have been compiled showing increased daily production, but insufficient time has elapsed since the general use of the gas-lift for ultimate yields to be available. However, assuming ultimate yields equal to other producing methods, the removal of the oil in a shorter space of time would result in greatly reduced operating costs.

Lowering of Oil-gas Ratios.—During the flowing life of a well, the oil-gas ratio may be reasonably controlled by beaning, variation of tubing sizes and depths, etc., but at best these ratios are usually high.

When a well is placed on the gas-lift, lowering of formation gas-oil ratios usually results. This is shown clearly in Fig. 1, which shows a well in which the gas was introduced while the well was still flowing. The result was a slight increase in production and a marked decrease in the formation gas-oil ratio, together with a slight decrease in the casing pressure. With the tubing depth unchanged, the well started taking gas as soon as the line pressure equalled the casing pressure. The casing

pressure did not drop much below its normal trend after the introduction of the gas, the slight break shown on the chart being due to a change in beans on the well.

The immediate drop in the formation gas-oil ratio was apparently largely due to the change in rate of production and the fact that the introduction of gas made it unnecessary for gas for lifting purposes to by-pass the oil to enter the hole. The continued decline in back-pressure possibly had some effect in further reducing the gas-oil ratio, but it will be noted that the same gradual drop in casing pressure prior to the introduction of gas was accompanied by an increase in the gas-oil ratio. On this property the gas-lift has been uniformly successful in reducing gas-oil ratios of wells producing from three different sands of different characteristics. Similar results have been obtained in another field operated by a different company. In every instance the effect of the gas-lift has been to moderately reduce back-pressures, but the reduction of back-pressures by changes of beans or natural decline did not have the same effect on the wells while flowing. It is the opinion of the writer, based on these and other observations, that effective back-pressures on the sands are not the only factors responsible for variations in gas-oil ratios. Steady rate of flow is undoubtedly important, and it is also indicated that in flowing wells excess gas comes into the well with the oil because of its requirement for lifting the oil in the tubing. This is brought out more clearly in a heading well in which the fluid rises rapidly in the casing and then waits for sufficient gas to accumulate to start the well flowing.

It is interesting to note that one company has not generally experienced a drop in formation gas-oil ratios in wells placed on the gas-lift. This company uses large tubing but has held the circulated gas to a minimum. Decreased ratios have been noted, however, when the circulated gas is increased. It therefore appears that the use of tubing small enough to prevent slippage and to require only a reasonable amount of gas circulation with normal friction is necessary to secure definite results in lowering formation gas-oil ratios even though the daily production is slightly lower. These methods coincide with those recommended above as a means of securing greater mechanical efficiency.

There has been considerable discussion regarding the use of the gas-lift as a means of varying back-pressures, but these variations are limited to a narrow range unless beaning is resorted to. When a well is on production, it is not always practical to shut down and change tubing sizes, and with a given tubing size suitable for good operating efficiencies, the writer has not found it possible to appreciably vary the back-pressure on the sand either by raising or lowering the tubing or by varying the amount of gas circulated. Lowering the tubing increases the operating pressure in amounts approximately equal to the decrease in fluid head.

Increasing the volume of gas circulated increases the friction to offset the benefits of increased aeration.

Result of Lowered Gas-oil Ratios on Ultimate Yields.—The gradual increase in production of the well shown on Fig. 1 was not caused by any

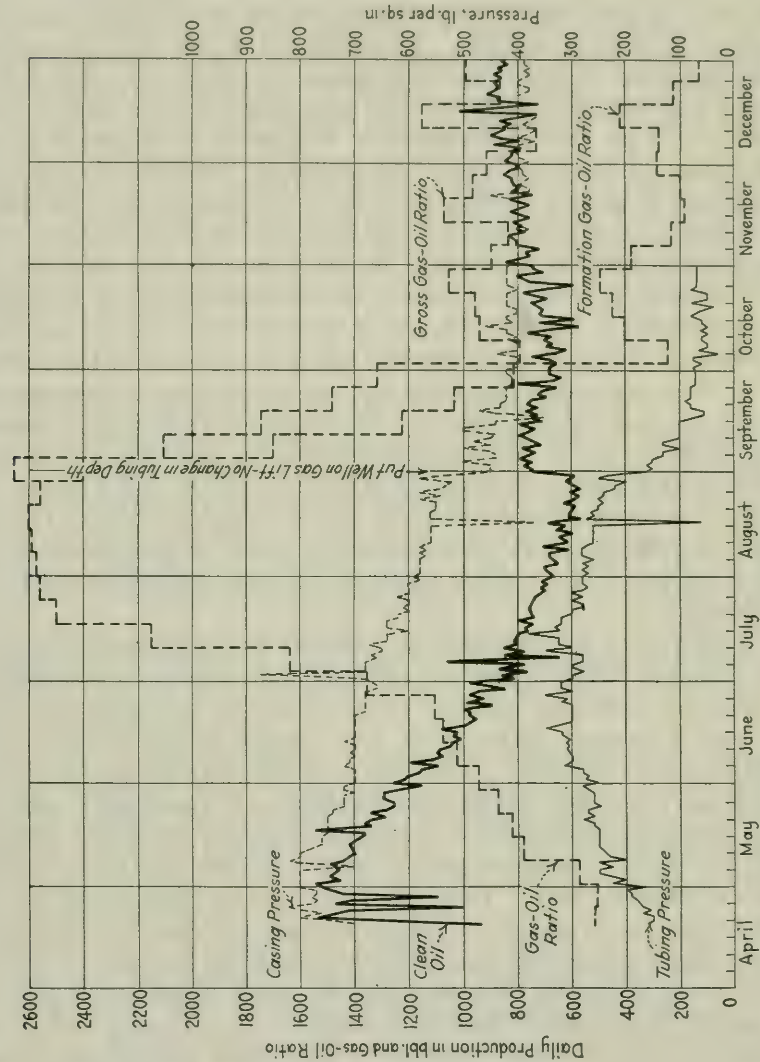


FIG. 1.—CHANGE IN GAS-OIL RATIOS FOLLOWING INTRODUCTION OF THE GAS-LIFT IN A FLOWING WELL.

variation in the amount of gas circulated or change in well equipment. The results of this well indicate a much greater ultimate yield than would normally be expected from a well of its initial output, and in addition show the value of a high-pressure plant for use of the gas-lift early in the

life of the well. An exactly similar condition was noted in the adjacent well, which was put on the gas-lift at the same time.

The next adjacent well (upstructure) was not put on the gas-lift but its production steadied and climbed slightly after the installation of the gas-lift in the wells mentioned above. A similar condition was noted in the well shown on Fig. 2. This well was on the beam in a different sand

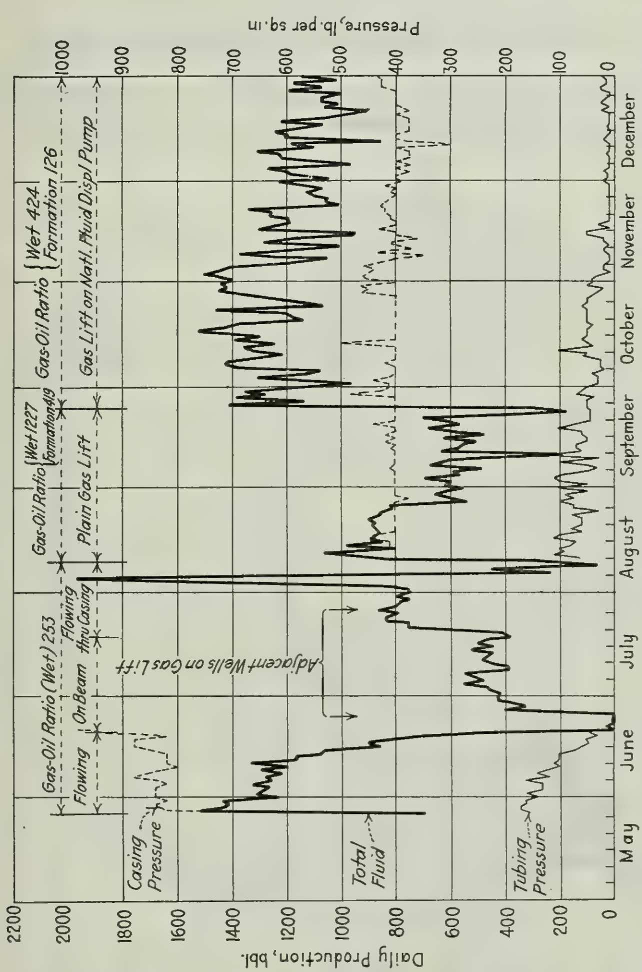


FIG. 2.—FLOW STARTED IN A WELL ON THE BEAM AFTER SURROUNDING WELLS WERE PLACED ON GAS-LIFT.

and it started to flow again after the wells surrounding it were placed on the gas-lift. The reason for the high gas-oil ratio while on the plain gas-lift, was the tendency of the well to head on account of water intrusion. This was remedied by the installation of the "fluid-displacement pump," which is described later.

These examples indicate that the conservation of gas in any one or more wells helps all of the wells in the same sand to produce more oil.

Fig. 3 shows a flowing well which started out with a very steady decline and then dropped rapidly. The gas produced exceeded the amount required for flowing the well until the gas production fell below the point A, after which the volume of gas was insufficient to flow the oil and the production dropped. It is evident that the use of the gas-lift

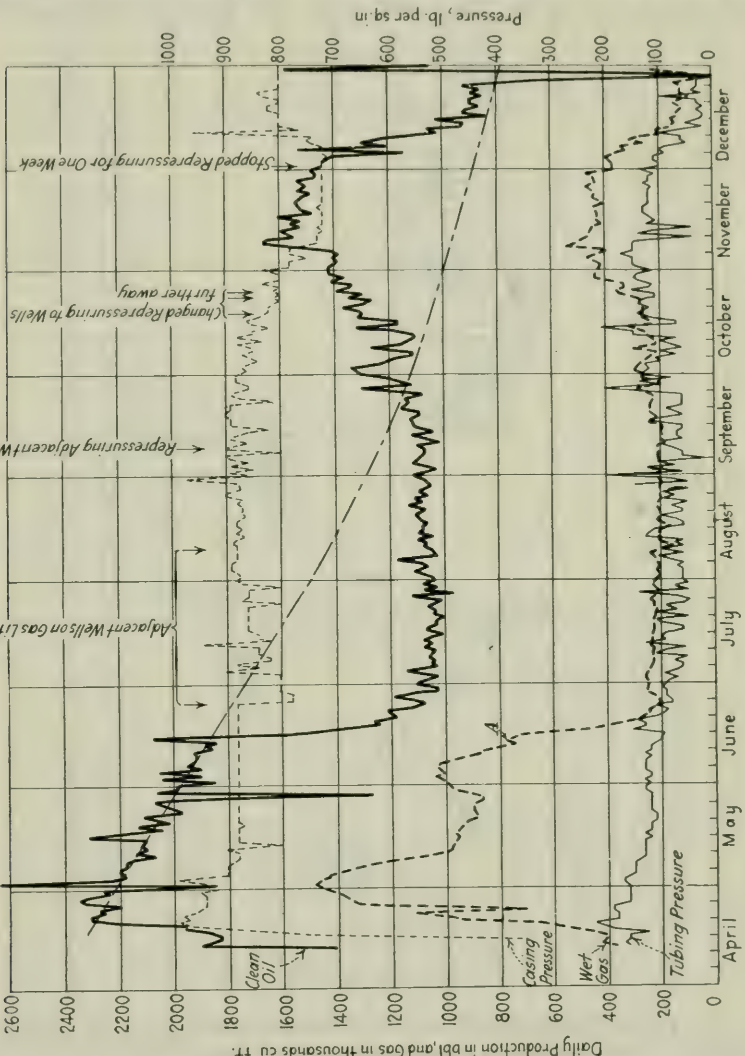


Fig. 3.—Casing pressure prevented use of gas-lift in this well.

at this point would have held up the production, which was suffering from lack of gas only, but the well could not be put on the gas-lift because of the 900-lb. casing pressure. The increase in the latter part of the year was due to repressuring which is explained elsewhere.[1]

[1] This volume, page 299.

Recent reports indicate that it is the consensus of opinion of engineers in all parts of the country that ultimate recoveries can be increased by the conservation of gas during the early life of the wells. This cannot be proved until new fields, now being developed with gas conservation in mind, have reached depletion. However, if the theory is accepted universally and the gas-lift can be proved to reduce oil-gas ratios, the result should be obvious.

Improvement of Gas-lift Equipment

During the last five months, the Marland Oil Co. of California has been trying a new device called a "fluid-displacement pump," which has

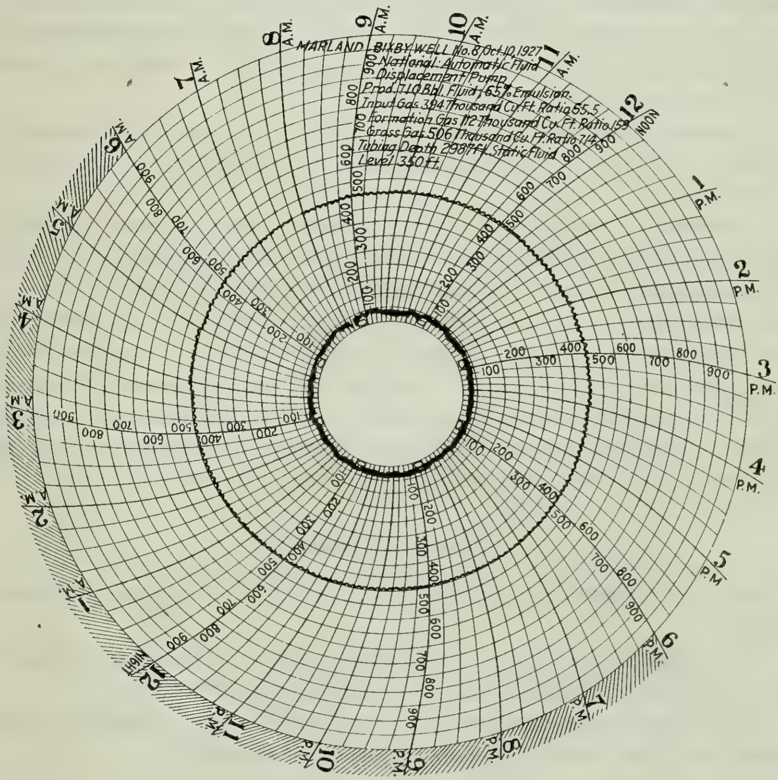


Fig. 4.—Pressure chart of a well on the fluid-displacement pump.

shown very encouraging results and is now being tried by several other companies. This device is run on the bottom of the tubing with either a packer or double string so that no gas pressure can reach the fluid. The fluid rises in the tubing through a valve until it approaches its static level and ceases to have sufficient upthrust to overcome the gas pressure exerted downward on the smaller gas valve, thereby opening this valve

and seating the oil valve, as both are on the same stem. The gas which is introduced between the casing and tubing enters the gas valve and lifts the column of oil in the tubing. When the top of the column of oil reaches the surface, the gas starts to expand, reducing its pressure so that the upthrust of the oil again opens the oil valve and seats the gas valve, repeating the operation. The results obtained with this device to date indicate that it or some similar device will go a long way toward solving many of the present difficulties in gas-lift operations.

As a means of showing how improvements to the gas-lift methods may solve many of the present problems, the following notes are given on the advantages of the fluid-displacement pump tried out on the Marland properties:

1. *Reduced Volume of Circulated Gas Required.*—On one gas-lift well the gross gas-oil ratio was reduced from 1227 to 424. This was typical of results on several wells (see Fig. 2).

2. *Reduced Viscosity of Emulsion.*—Due to the fact that the gas does not mix with the oil to any great extent, the emulsions are less viscous and less stable.

3. *Increased Production.*—Wells changed from ordinary gas-lift to fluid-displacement pump have shown increased production. This is due to elimination of gas pressure on the fluid (see Fig. 2).

4. *Better Control.*—Due to the automatic control of the gas entry into the tubing, the flow of gas is easy to regulate without the use of other control devices. Fig. 4 shows a tubing and casing pressure chart of a well on the fluid-displacement pump. Each variation in pressure represents a displacement. The meter charts for this well show a very even flow of gas to the well with only manual control.

Present Problems

Two very important problems are facing the production engineer at present:

1. To develop a safe and economical method of starting the gas-lift early in the life of wells flowing with high casing pressures.

2. To develop a method of producing small wells on gas-lift so as to compete with the operating costs of pumping methods.

DISCUSSION

C. E. Beecher,* Bartlesville, Okla.—Mr. Bell has submitted some figures to show the barrels produced per horsepower by the gas-lift method, and by pumping with gas engines and with electric motors. I believe gas-lift equipment is usually so operated that the rated horsepower is approached most of the time, while on most pumping wells the gas engine or electric motor has a rated horsepower greatly in excess of that developed or used while pumping. It is common practice to install a 40-hp. gas engine or

* Production Engineer, Empire Gas & Fuel Co.

a 15 to 30 or 25 to 50-hp. motor for handling a well. The greater horsepower is required for pulling rods, tubing, and working on the well, but not for pumping. A 40-hp. gas engine may develop only 20 hp. or less while pumping a well and the same would apply to a 30-hp. electric motor. If a well is being produced by the gas-lift, additional horsepower in some form must be provided to handle the tubing and do such other work on the well as may be necessary. The point I wish to bring out is that the horsepowers compared should be on the same basis.

A. H. Bell.—The references to pumping-engine and compressor-plant horsepower were made for the purpose of showing the comparative investment required rather than for the purpose of showing the actual horsepower developed, as naturally every pumping well will develop a different horsepower depending on the depth, volume of fluid, viscosity, etc.

The statement implying that it was not considered good practice to flow the oil between the tubing and casing, was made with reference to California only and as applied to California conditions.

Chapter II. Gas-oil Ratios

The "Gas Factor" as a Measure of Oil-production Efficiency

By Lester C. Uren,* Berkeley, Calif.

(Fort Worth Meeting, October, 1927)

Field studies and laboratory research have established the fact that the expulsive force which drives petroleum into wells, from the reservoir sands in which it is stored by nature, is primarily an expression of the energy latent within compressed natural gas dissolved or occluded in, or otherwise associated with the oil. Each barrel of oil produced is forced into the recovery well by the expansive energy of a certain volume of compressed gas, originally stored with the oil in the pores of the reservoir rock; and each cubic foot of gas so produced with the oil and expanded to atmospheric pressure reduces by so much the total natural energy available for oil expulsion. This relationship between the volumes of gas and oil produced has seemed so important that petroleum production technologists have come to regard the "gas-oil ratio," or the "gas factor" as it has been more conveniently termed, as a measure of oil-production efficiency. Different methods of oil recovery and production devices are now compared on this basis and estimates of ultimate recovery obtainable through their use are considered by many to be inversely proportional to the values of their respective gas factors.

The writer has been among those who have given support to a widespread movement toward a proper recognition of the significance of the gas factor as a guide in the control of producing oil wells, and does not wish to oppose its more extended application. It seems necessary, however, in view of the almost elemental faith with which the principle of the gas factor has been received in many quarters, to point out that it is a most complex factor, and one which cannot be regarded as an absolute index of production efficiency without due regard to other contributing factors by which it is influenced to an important degree.

Variables Influencing Gas Factor

The mere recording of a low gas factor, obtained through the use of some method or device, does not necessarily imply efficient oil production; and conversely, a high gas factor does not always signify inefficient recov-

* Professor of Petroleum Engineering, University of California.

ery. Other variables must also be taken into consideration, and when these are given due weight, it may at times be found that the well producing with a relatively high gas factor is the more efficient. It is the purpose of this paper to review factors which influence the gas-oil ratio, explaining the effect of each, in the hope of arriving at a more complete understanding of the significance and range of application of this useful index of production efficiency.

Influence of Decline of "Field Pressure"

It is well known that the volume of gas at atmospheric pressure which may be produced from a cubic foot of formational gas is a function of the pressure with which the gas is stored in the reservoir sand, and yet this fundamental principle seems to have been lost sight of by many who indiscriminately compare gas factors obtained from wells of all ages and producing under widely varying field pressures. If a certain amount of energy is required to force a given volume of oil through the reservoir sand into a well, it is clear that provision of this energy will require the expansion of a larger volume of gas when the field pressure is low than when the formational gas exists under relatively higher pressure. Consequently, it is natural to expect that the gas factor will range progressively to higher values as the well ages, or as a field is drained of its gas in the normal course of development.

In comparing the efficiencies of different wells, we are interested not so much in the actual volumes of gas produced with the oil, but rather with the energy consumption represented in the expansion of this gas from the pressure at which it existed in the oil sand. When reduced to the energy basis of comparison, it will often happen, when the efficiencies of two wells are compared, that the one showing the highest gas factor will be producing its oil with a lower unit energy consumption. For example, suppose that, in case No. 1, a well is producing with a gas factor of 1500 cu. ft. per bbl. from a formation pressure of 250 lb. per sq. in., while in No. 2, 1000 cu. ft. of gas is produced with each barrel of oil, but the formation pressure is 500 lb. per sq. in. Here well No. 2 has the lower gas factor, but is producing its oil with an energy consumption of approximately 1.4 times that of No. 1. It is submitted that a more appropriate basis of efficiency comparison would be the product of the gas factor by the number of times the volume of the gas has increased in expanding from the formation pressure to that at which its volume is measured.

Influence of Advancing Age of Wells

In addition to declining formational pressure, the advancing age of a well is accompanied by the development of oil-drained channels within the more permeable component members of the productive zone, through

which gas finds a ready means of escape to the wells. Gas is thereby enabled to pass through the sands from points remote from the wells, without comparable movement of the oil. Oil entering the wells is thus produced in association with gas of which only a small portion may have had any influence in bringing about its movement through the sand. The gas factor is by this means greatly increased.

There would seem to be no means of estimating, with any degree of accuracy, the extent of gas channeling, though it unquestionably increases with the age of the wells and with the amount of oil drained from the sands. Intensity of development as exemplified by close spacing of wells will no doubt also have an important influence in rapidly developing gas channels. Intersection of drainage cones about closely spaced wells may quickly develop oil-drained channels through which gas is free to migrate over great distances.

If these considerations are valid, the conclusion is inescapable that lapse of time, resulting in partial drainage of oil and greater freedom of movement of gas throughout the productive formation, will lead to gradual increase in the gas-oil ratio of producing oil wells.

Influence of Flow Resistance Offered by Reservoir Sand to Movement of Oil

The energy necessary to force oil through the reservoir sand over a given distance to a well outlet will, of course, depend on the resistance to flow offered by the reservoir sand. Fine-grained sands having small pore spaces and composed largely of angular grains of rough-surfaced minerals offer materially greater resistance to passage of oil than coarser and more porous media composed of well rounded smooth-surfaced minerals. The flow resistance is also influenced to an important degree by the viscosity and surface tension of the oil, low values for these properties permitting greater freedom of movement of the oil through the restricted apertures of the reservoir sand.

The resistance to movement offered by the sand,[1] will primarily determine the amount of energy necessary to accomplish expulsion of the oil, though the rate of flow and the distance over which the oil must travel will also be determining factors. High sand resistance resulting from either small size of sand pores, high viscosity of oil, high rate of flow or long transmission distance, will tend toward increase in the gas factor, and vice versa. Any means of reducing the sand resistance to flow of oil and gas, such as forming cavities about the wells within the oil sand, should also be effective in reducing the gas factor. Obviously these physical variables cannot be ignored in estimating the relative efficiencies of producing wells by comparison of their respective gas factors.

[1] For a discussion of the forces resisting expulsion of petroleum from reservoir sand, see a paper by the author in *Natl. Petr. News* (Feb. 9, 1927) 67.

Influence of Release of Gas from Solution in Oil

The solubility of gas in petroleum decreases in straight-line relationship with pressure. Accordingly, as pressure is released within an oil-bearing formation by production of a part of the oil and gas, much of the remaining gas, though originally in solution in the oil, assumes gaseous form and exists within the oil in the form of minute bubbles. These occluded gas bubbles become trapped within the sand pores and it is by reason of their continued expansion that oil is ejected. Experimental data indicate that the fluids move through the drainage channels in chains of alternating oil filaments and gas bubbles, the latter continually expanding with the decline in pressure as they approach the well outlets.

While expanding gas bubbles are thus largely responsible for the ejection of petroleum from the sands, it is also true that they interpose considerable resistance to flow. As each gas bubble passes from pore to pore of the reservoir sand through the restricted communicating channels, it must be subjected to considerable distortion, a requirement which in the aggregate occasions great energy loss.[2] Furthermore, as the pressure declines and the occluded gas bubbles increase in size, the oil becomes more viscous and the energy necessary to force the fluids through the sand increases.

For a given pressure drop, less energy is consumed if the final or delivery pressure is high than if it is low, for the mean viscosity of the oil will be lower, the gas bubbles will have a smaller average size and they will therefore be more easily forced through the sand. If an elevated delivery pressure is maintained, there is a relatively greater percentage of the space within the drainage channels available for movement of oil and consequently more oil flows. This is in all probability why maintenance of back-pressure on a well permits of production of oil with a lower gas factor than is possible when the gas is fully expanded, and explains also why the ultimate production of oil is increased thereby.

It is to be noted, however, that the advantages gained by maintenance of an elevated delivery pressure are offset to some extent by the energy latent within the gas bubbles not fully expanded on admission to the well. That is, the saving in energy secured by establishing conditions which limit the size of the gas bubbles within the oil, and the energy loss occasioned by permitting them to escape from the oil sand before they are fully expanded, are opposing factors, and maximum efficiency can be secured only by obtaining a proper balance between them. In other words, for any given conditions, there is a certain back-pressure or delivery pressure which, if maintained, will result in a minimum energy loss and a maximum ultimate oil yield.

---

[2] For a discussion of the influence of occluded gas bubbles on the movement of oil through reservoir sands, see an article by the author in *Natl. Petr. News* (Jan. 26, 1927) 71.

Experiments conducted under the supervision of the writer have indicated the essential truth of this theory. In these experiments, gas-

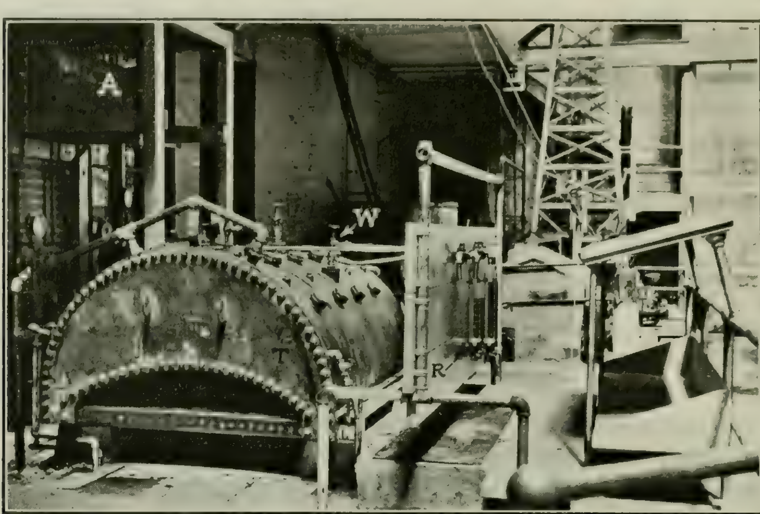


FIG. 1.—PRESSURE-DRAINAGE APPARATUS.
A = absorber; T = sand-filled pressure tank; W = miniature well; R = graduated oil-receiving tubes.

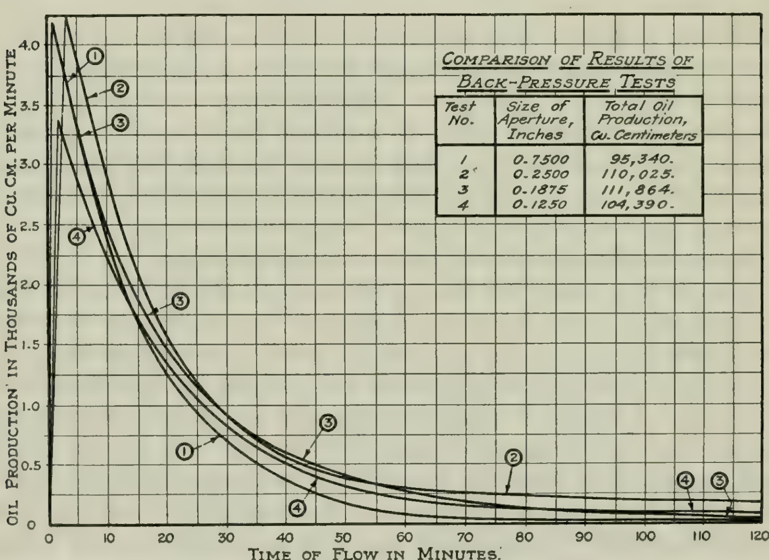


FIG. 2.—DECLINE CURVES OBTAINED IN EXPERIMETAL BACK-PRESSURE TESTS.

saturated oil, contained within the pores of an unconsolidated sand in a steel pressure tank, was permitted to escape through a miniature well penetrating the shell of the tank (Fig. 1). In successive experiments,

sand, oil and initial pressure conditions were maintained precisely alike, except that the miniature well was required to discharge the oil under variable, controlled back-pressures. Variation in back-pressure was obtained by inserting in the flow line small "beans" or flow plugs having different-sized apertures. The rate of oil flow and total yield was accurately measured in each experiment and production graphs constructed which closely resemble production records plotted from actual field data. Fig. 2 presents four of the graphs thus secured. The inserted table on Fig. 2 indicates the total yield of oil for each of four different sizes of "beans" (*i. e.*, for four different back-pressures). The 0.1875-in. aperture gave the maximum yield, while smaller and larger apertures resulted in a lower ultimate yield. The most efficient back-pressure resulted in an ultimate production 17 per cent. in excess of that which was secured with the least efficient.[3]

The writer has seen comparable field data secured from actual producing wells, which prove without doubt that controlled back-pressure will result in increased oil recovery, and that there is a certain definite pressure for every set of conditions which will result in maximum yield. Determination of this most efficient back-pressure is admittedly a difficult problem, and even though we are able to determine it precisely for a given well at a particular time, it does not remain constant, but continually changes as the formation pressure and volume of oil-flow decline.

Application of back-pressure to producing wells results in reduction of the gas factor, as explained above, the volume of gas produced with each barrel of oil decreasing as the back-pressure increases. Up to a certain point, this conservation of gas results in increased ultimate recovery, but beyond this point the energy lost in gas not fully expanded, as discharged from the well, exceeds that conserved by reduction of the gas factor, and thus the ultimate recovery is diminished. Too low a gas factor, if obtained by increasing the back-pressure above the critical point, may therefore be indicative of reduced production efficiency rather than the reverse.

Influence of Recovery Rate on Production Efficiency

Experiments on the resistance offered by sand to the flow of oil containing occluded gas bubbles through its pores have shown that the resistance to flow varies with some power of the rate of flow in excess of unity. That is, to double the rate of flow, something more than twice as much energy is required. It follows, therefore, that gas energy may

[3] The experiments were performed by W. H. Morrison, E. Neal, S. Holmes and H. Pyle, senior petroleum engineering students in the University of California, with the assistance of R. S. McIntyre, instructor in petroleum engineering, University of California.

be conserved by reducing the rate of production of oil wells, and if a producer is content with a lower production rate he may, within certain limits, secure a greater ultimate recovery from his property. This would normally be accomplished by applying back-pressure, which would result in a lower gas factor.

Influence of Well Spacing

It has been shown that gas channeling through oil-drained spaces within the sand is responsible for increase in the gas factor, and that this increase is accelerated as drainage proceeds. Such action is promoted by close spacing of the wells, overlapping drainage cones permitting extensive gas migration over wide areas.

It has also been demonstrated that the energy loss in moving oil through the sand is a function of the rate of flow, increasing as the flow increases. Experimental data indicate that due to the radical flow characteristics of fluids draining into wells, the rate of flow is greatly increased in the immediate vicinity of the walls of the wells. Computations indicate that more than one-half of the total energy loss in moving oil through sand over a 300-ft. drainage radius toward a 6-in. well occurs within 10 ft. of the walls of the well. Every additional well drilled within the drainage radius of another well thus becomes a center of rapid gas expansion and is therefore to be regarded as a liability in the gas-energy balance sheet. Providing the wells are not spaced beyond oil-drainage radius of each other, the fewer the number of wells used, the less rapidly will the oil be drained; and because of the lower average rate of flow of fluids through the sands, the energy consumption per barrel of oil produced will be lower. Hence the ultimate recovery of oil will be greater for widely spaced wells than for closely spaced wells, providing the interval between wells does not exceed the natural radius of oil drainage.

To many this will seem to be a fallacious conclusion, for it is directly contrary to generally accepted belief. The writer, however, has additional proof in the results of a series of experiments conducted in the pressure-drainage tank mentioned in a previous section.[4] Tests performed in which the initial sand, oil and pressure conditions were identical, but in which the number of wells used in draining the tank varied. Table 1 gives the results. Inspection of the data will show that the ultimate recovery decreased steadily as the number of wells increased, except that two wells produced more than one.

Other evidence pointed to the conclusion that a single well did not completely drain the tank, but that two wells were sufficient for the purpose and additional outlets beyond this number were within oil-

[4] These experiments were performed by A. B. Stevens, C. A. Steiner, J. M. de la Garza and A. Bartels, senior petroleum engineering students at the University of California.

drainage radius of each other and were therefore productive of gas wastage and energy loss.

TABLE 1.—*Results of Pressure-drainage Tank Experiments to Determine Influence of Well Spacing on Ultimate Recovery*

Number of Wells Producing	Total Recovery of Oil Cu. Cm.	Percentage Recovery
1	103,750	25.7
2	117,100	29.0
3	105,700	26.1
4	102,500	25.4
5	101,100	25.0
6	99,300	24.6

The results of these experiments and the theoretical considerations outlined above lend support to the theory that close spacing of wells, as represented by "town-lot" development in many Western and Mid-Continent oil fields, is wasteful of gas energy and results in a lower ultimate recovery of oil than would be possible by wider spacing. When wells are drilled within oil-drainage radius of each other, the prevailing gas factor will be generally higher than in areas in which a proper interval between wells is maintained. The writer believes that additional proof of this theory may be found by a close scrutiny of production data in fields in which variable spacing of wells in different comparable areas has been practiced.

Influence of the Production Method

There is no doubt that the production method employed, the degree of well control and general production technique of the operator, have an important influence on the gas factor and on gas-energy consumption. A naturally flowing well is inefficient in this respect, and leads to gas factors higher than normal, because the formational gas is required not only to drive the oil into the well, but also to lift it to the surface. In the case of a 3000-ft. well, about 930,000 ft.-lb. of work must be done in merely lifting each barrel of oil to the surface after it enters the well. Assuming 100 per cent. efficiency, a well producing, say, 1000 bbl. per day from this depth, must thus continually expend 19.57 hp. It is known, however, that due to gas slippage and other inefficiencies, flowing wells have a very low efficiency, seldom exceeding 20 per cent. and often much lower. Assuming 20 per cent. efficiency, the actual power consumption is nearly 100 hp. The formational gas must furnish this energy in naturally flowing wells, and hence their gas factors are higher than when other methods of lifting the oil are employed.

Gas-lift wells can be considerably more efficient in so far as consumption of formational gas energy is concerned, for here external energy in

the form of gas compressed and forced down into the well supplies the greater part of the energy necessary to lift the oil. It is to be noted, however, that even in a gas-lift well, the formational gas must provide a part of the energy necessary to lift the oil to the surface. If the volume of gas forced down from the surface be measured and subtracted from the total volume of gas reaching the surface, the formational gas factor—in which we are here primarily interested—will be found materially lower than in naturally flowing wells producing under comparable conditions.

For maximum efficiency in any type of flowing well, it is important that the well be tubed to the proper depth. Tubing depth not only influences the lift efficiency, but may, under favorable circumstances, have a favorable effect in reducing gas channeling in the sands about the well.

A pumping well may operate more efficiently than any other in so far as consumption of natural gas energy is concerned, for here the formational gas is called upon to supply only enough energy to force the oil into the well, and mechanical power employed in lifting the oil to the surface is supplied entirely from external sources. If flow of gas between the well tubing and the enclosing casings is prevented, and the pump is placed at a suitable level in the well to prevent channeling of gas toward the well in the reservoir sand, a pumping well may operate with a lower gas factor than a well operated by any other means.

In some fields, edge-water pressure aids materially in forcing the oil into the wells, the oil being produced with comparatively little formational gas. It should be recognized in such cases that we are dealing with a radically different type of expulsive force and that the gas factors obtained in wells producing by this means are in no sense comparable with those obtained in other fields where production is secured entirely by the expulsive force of expanding natural gas.

Influence of "Economic Life" of Oil Property in Determining Most Profitable Gas Factor

While the ultimate oil recovery will be increased through application of the proper degree of back-pressure to producing oil wells, the time within which production is secured is ordinarily extended over a longer period than when no back-pressure is used; and it will perhaps happen that the critical back-pressure giving maximum ultimate oil recovery will result in unduly prolonging the period of exploitation. Under the highly competitive organization of the present-day oil-producing industry, an operator may find it expedient, or more profitable, to accept a smaller total yield from his property in a short period of time than to extend operations over a longer period for a greater ultimate yield.

The "economic life" of an oil-producing property,[5] or the total life-period as determined by the rate of production yielding maximum profit—a conception which involves consideration of the cost of production, the selling price of oil, the interest rate demanded on capital and many other economic as well as physical factors—is inextricably interwoven with the whole subject of gas conservation. From the standpoint of the producer, the rate of production, which is determined by the back-pressure employed and the resulting gas factor, must be an economic one; that which will result in maximum ultimate profit.

The gas factor which results in maximum ultimate oil yield will ordinarily not be the one that is productive of greatest ultimate profit to the producer. The oil conservationists and industrialists must therefore seek a middle ground between these two viewpoints in determining what constitutes a reasonable recovery efficiency that will be in accord with the public interest in a rapidly diminishing national resource, and yet fair to the producer from the economic standpoint. Price must control in the final analysis; higher price will compel more efficient recovery, while a depressed price structure will encourage production inefficiency.

Summary

The objective of this paper is to emphasize the fact that the gas-oil ratio or gas factor of a producing oil well is not a reliable index of production efficiency unless it is considered in conjunction with various other contributing factors. The several variables which have a bearing on the magnitude of the gas factor are reviewed and their influence is explained.

The discussion and data offered apparently justify the following conclusions:

1. The volume of gas produced with a unit volume of oil is not in itself a measure of production efficiency unless the pressure from which the gas expanded to its measured volume is taken into account. The gas factor is of interest only as a measure of energy consumed and has no significance until considered in relation to the initial pressure at which it existed within the reservoir sand. Release of pressure within the reservoir sand, occasioned by production of oil and gas, results normally in a gradual increase in the gas factor. It is suggested that a better basis of comparison for oil-well production efficiencies would be found in the product of the gas factor by the number of times the volume of the gas has increased in expanding from the formation pressure to that at which it is measured.

[5] For a more extended discussion of the factors controlling the economic life of oil-producing properties, see an article by the writer in *Oil Field Engng.* (November, 1926) **49,** 86.

2. The flow resistance offered by the reservoir sand to passage of oil through it will primarily determine the energy necessary to accomplish its translation, and thus will influence to an important degree the magnitude of the gas factor. Flow resistance is a function of the sand permeability, which in turn depends on the size of sand pores, texture of the mineral-grain surfaces, and viscosity and surface tension of the oil. The rate of flow and distance traversed are also factors of importance in determining the sand resistance.

3. Release of gas from solution in the oil, resulting in increase in oil viscosity and in formation of minute gas bubbles which remain occluded in the oil within the sand pores, has an important influence in increasing the sand resistance to flow. For this reason, the energy necessary to cause flow, and the gas factor, are increased as the pressure declines and the gas is released from solution in the oil. The resistance to flow is further increased as the occluded gas bubbles grow in size with continued release of pressure.

4. Advancing age of the wells, with attendant growth in the extent of oil-drained channels within the reservoir sand, promotes channeling of the gas from points remote from the wells, without comparable movement of the oil. Such oil as is produced is therefore accompanied by a greater quantity of gas than during the early period of development when gas channeling is not a factor of such great importance.

5. Close spacing of wells also promotes channeling of gas with a resulting high gas factor. Rapidity of production which results from crowding of wells leads to high gas-energy consumption and a higher gas factor than would be possible with properly spaced wells. Each additional well drilled within oil-drainage radius of other wells is a gas liability and leads to a reduction in ultimate oil recovery.

6. The method of production and technique of well control have an important influence in determining the gas factor, occasioned chiefly by the extent to which the formational gas is relieved of the necessity of lifting the oil to the surface, and the precautions taken to prevent channeling of the gas in the vicinity of the wells. In this regard, free-flowing wells are least efficient, gas-lift wells are more efficient, and pumping wells most efficient. It is important that the well be tubed to a suitable depth, irrespective of the method of production employed.

7. Application of back-pressure to producing wells provides a means of reducing the gas factor by reducing the rate of flow of fluids in the reservoir sand, reducing the viscosity of the oil and minimizing growth of the occluded gas bubbles within the oil as they approach the wells. For any given set of conditions, there is a certain back-pressure which, if maintained, will result in maximum ultimate recovery of oil. Either higher or lower back-pressures will result in decrease in the ultimate recovery. This most efficient back-pressure is not constant throughout

the life of the well, but decreases as the formation pressure and rate of production decreases.

8. The most efficient back-pressure and gas factor, from the standpoint of ultimate recovery, are not usually those which are productive of maximum ultimate profit to the producer. The "economic gas factor" is one that must be arrived at by a proper balancing of considerations which determine the financial profit to the producer with considerations of conservation of oil resources in the public interest. The selling price of petroleum will determine how far the producer may go in meeting the conservation issue.

9. Efficiency in the use of gas energy in oil production depends primarily on proper spacing of wells, timeliness of development, maintenance of a suitable rate of production and the use of production methods which will utilize as large a part of the expulsive energy of the gas as may be possible, in forcing oil through the reservoir sands into the wells.

Effect of the Gas-lift on the Gas Factor and on Ultimate Production

By E. O. Bennett,* Fort Worth, Texas

(Fort Worth Meeting, October, 1927)

When oil is taken from a subsurface structure it is generally accompanied by gas. The gas thus produced represents the lighter hydrocarbons present in the original petroleum accumulation, which are insoluble at the reduced pressures created around a well when it is producing. In some cases the gas accompanying the oil may come from a gas-bearing stratum not in immediate contact with the oil. The amount of gas from the formation accompanying each barrel of oil is called the natural gas factor.

Energy Causing Well to Flow

The force causing the flow of fluid into a well when it is drilled into an oil-bearing structure is the pressure differential between the well bore and the formation. A pressure differential between the formation and the well may be set up in three different ways, as follows: (1) pressure due to gas in solution or in contact with the oil, (2) hydrostatic pressure due to water in contact with the oil (it may be either bottom or edge water); (3) pressure difference due to force of gravity.

The greatest source of energy for producing oil from most oil fields, and the one over which the greatest control can be exerted, is the potential energy in the gas under pressure in the formation. In any pool there is but a definite amount of gas available. Part of this gas may be in solution and a part in contact with oil. The amount of gas in solution in each barrel of oil depends on the pressure and temperature in the formation and the characteristics of the oil. Whether the gas is in solution or in contact with the oil it is necessary to use the energy it contains as efficiently as possible in order to obtain the greatest ultimate recovery from the pool. Bush[1] states:

> Gas being the most efficient aid in moving the oil, it is important to prevent more of it from escaping than is necessary to remove the maximum amount of oil from the sands. The conservation of this energy is far more important to the producer of oil than his returns from sales of gas to distributing companies. The flowing life of the well is the most profitable period, and keeping the gas-oil ratio low, or keeping the

---

* Chief Production Engineer, Marland Oil Co. of Texas.

[1] R. D. Bush: Conservation of Gas in the Production of Oil. Publication of California State Mining Bureau (March, 1927) **12.**

gas in solution as long as possible, prolongs the flowing life of the well and moves more oil from distant parts of the sand, thereby increasing the total ultimate recovery of a property or field. Laboratory experiments have proved that the viscosity of oil is greatly reduced with gas in solution, and when this gas is under several hundred pounds pressure, the viscosity of the oil tested was said to be about the same as that of gasoline. When the gas escapes the viscosity increases, and oil is left in the sand to be recovered only by expensive methods and at a very slow rate.

The amount of energy required to produce a barrel of oil from a well depends on several factors, some of which are controllable and some uncontrollable. The controllable factors are: (1) rate of production; (2) pressure on the formation. The uncontrollable factors are: (1) porosity of formation; (2) permeability; (3) viscosity of oil; (4) surface tension of oil.

The factor having the greatest effect on the rate and ultimate production of a well is the pressure held upon the producing formation. The rate at which the energy is dissipated is governed by the flow differential. This, in turn, is controllable over certain limits by back-pressure regulation. Millikan[2] says:

> So high a pressure differential between the sand and the well may exist that the gas will move through the sand at a greater velocity than that at which it will carry the maximum amount of oil. As the pressure declines, the velocity of the gas is reduced and smaller volume carries with it an equal or greater amount of oil, which results in a declining gas-oil ratio. Under these conditions if the velocity of the gas is reduced by increasing the pressure the amount of oil would be increased and the volume of gas per barrel of oil decreased. Excessive velocity of gas through the sand is affected by the size of the pores in the sand as well as the pressure differential, larger pores permitting an excessive velocity under conditions which would be normal in a finer grained sand.

Condition of Well under Back-pressure

The gas-lift has been given much study and discussion during the past year. It has been used primarily as a means of increasing the output of wells; and but little thought has been given to the efficiency of well flow with regard to ultimate recovery. Most gas-lift or air-lift installations have been put in with the view of getting maximum production and maximum mechanical efficiency in the flow line. Little attention has been given to the part of the well below the flow line. When compared to the efficiency of the well, the mechanical efficiency of the flow line is of secondary importance. To strive for mechanical efficiency in the flow line only will generally cause an economic loss in production.

It is true that with a high mechanical efficiency in the flow line, a smaller amount of gas is required to raise a barrel of oil than when low efficiency exists. If the amount of gas coming from the formation is ignored, the total production efficiency of the well may be very low, even with the very best mechanical efficiency in the flow line. The result of

[2] C. V. Millikan: Gas-oil Ratio as Related to Oil-production Decline. Petroleum Development and Technology in 1926, 147.

this condition is that while a fair rate of production may exist the well's ultimate recovery will be decreased. Efficient operators equip their wells with meters and gages on the input side. There are, however, very few who measure the discharge gas from the well. The difference between the output and the input gas is the amount taken from the formation. It is called the natural gas factor. The natural gas factor is the best criterion of the well's condition and should be given the most consideration at all times. A careful study of the decline of the natural gas factor will give valuable information regarding the ultimate recovery of a well.

The principle involved in applying the gas-lift or air-lift to producing an oil well is not new, nor is its application in the oil industry new. Some of its most important features are, however, given little consideration. The gas-lift may be called a mechanical means of controlling pressure on the producing formation. Under this condition the title of this paper might better be "Back-pressure and Its Effect on Gas Factors and Ultimate Recovery." Before discussing the use of the gas-lift and its relation to ultimate recovery, it is advisable to discuss the effect of pressure on the condition of the sand in the well during different stages of the life of the well.

Fig. 1 represents the condition of the producing formation around the well when the well is first drilled in. Approximately all of the gas in the formation is in solution in the oil and the formation is completely saturated. This is also evidenced by the fact that wells flow, where the pressure is suitable, as soon as the bit penetrates the formation. If a well is drilled in and allowed to produce unchecked a maximum differential is created between the formation and the well. This sudden release in pressure allows the gas contained in the oil to escape. Much of the escaping gas gets away without doing any work in moving oil to the bore of the well. The only work it can do then is to assist the oil through the tubing or casing. Such energy can better be supplied from the surface. In Fig. 1 the oil-drainage area into the well is: $D\pi \times A$, where D is the diameter of the well bore and A is the penetration into the producing formation. Then

$$Q = \frac{AP \times D \times \pi \times A}{R^n}$$

where

Q = the quantity of oil producing during a definite period of time.

AP = the difference in pressure between the formation and the well. (It is the rock or shut-in pressure minus the back-pressure on the formation.)

R^n = the resistance factor which governs the flow through a sand. It is governed by the porosity and permeability of the formation, the characteristics of the oil, and rate of flow.

When a well is first drilled in ΔP and A are both large and R^n is small. This indicates that, on account of the saturated condition at the well, the oil produced has but a short distance to travel and the production rate will be high. With a maximum saturation, maximum drainage area and low resistance, little work is required to move oil into the well. The result is that the well fills rapidly and imposes a pressure on the formation, on account of the hydrostatic head created. This pressure then decreases the differential or flowing pressure ΔP and keeps the gas dissolved in the oil from escaping at a maximum rate. As long as the flow rate from the well does not exceed the rate of influx into the well, the saturation next to

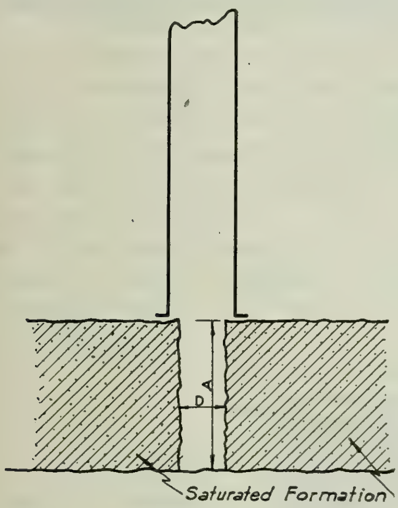


FIG. 1.—CONDITION OF PRODUCING FORMATION WHEN WELL IS FIRST DRILLED.

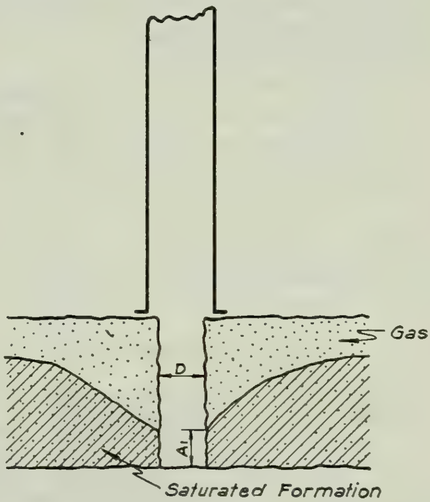


FIG. 2.—SHOWING DRAINED AREA THROUGH WHICH GAS CAN ESCAPE WITHOUT MOVING OIL.

the well will be great and the escape of free gas small. It is for this reason that oil is always produced with lowest gas factors at the flush stage of production.

As production is continued the oil must travel farther to get to the well. The resistance to travel from a distance increases very rapidly and the energy required increases in a corresponding amount. This requires more gas per barrel, since the pressure and energy contained in each cubic foot of gas also decreases. If the oil is continually removed at a rate approximating the flush stage, it is produced faster than it can enter the well. The result is that the space around the well is drained of oil and allows gas to escape very readily.

This condition is shown in Fig. 2. The upper portion of the formation near the well has been denuded of its oil and a large drained area is left through which gas can escape without moving any oil. The total drain-

age area for the oil to enter the hole now becomes $D\pi \times A_1$ and since A_1 is much less than A there is less opening for oil to flow into the well. The condition as shown in Fig. 2 can exist where the well is still in its early life but has been produced at too great a rate. It may also exist during the later life of the well when natural depletion has occurred. The quantity Q as before is $= \Delta P_1 \times D \times \pi \times A_1$. In this case ΔP_1 is large and A_1 is small. The product of these two may now be greater than it was in the first case. This would indicate a greater production rate. On account of the increased area for gas bypassing and the increased resistance to the flow of oil on account of the smaller drainage area and greater distance the oil must travel, the production actually becomes less and the gas factor increases.

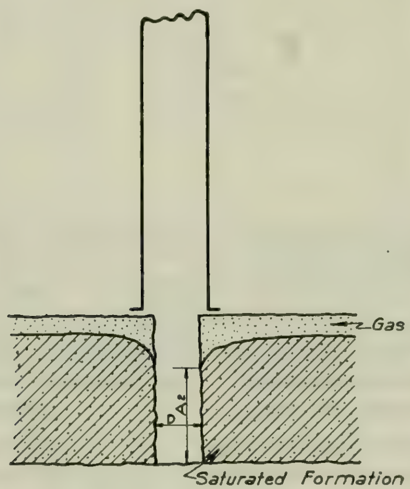


FIG. 3.—INCREASED OIL SATURATION AROUND WELL PRODUCED BY BACK-PRESSURE.

After a well has produced for a short time and the existing pressures are such that it will continue to flow naturally, the amount of gas escaping into the well, which does but little work in moving oil to the bore, is greater than the amount required to aerate the fluid column in the casing to the point where the pressures are unbalanced and the well flows. The result is that the oil is produced with a very high natural gas factor, a low producing efficiency, and the ultimate recovery from the well is decreased.

Fig. 3 shows the condition of saturation around a well which is produced under back-pressure or under a small flowing pressure differential between the well bore and the formation. In the initial stages of a well the sand is completely saturated as shown in Fig. 1. After rapid production the condition of saturation changes to that shown in Fig. 2.

Petroleum as found in a completely saturated formation is a hydrocarbon fluid composed of liquid and gases. When the condition shown in Fig. 2 has been reached and back-pressure is applied to the well, the gas, being highly compressible, is affected at a greater rate than the oil. Any increase in back-pressure, or decrease in differential pressure, causes a greater static pressure in the formation at the well bore. This increased pressure which can approach the rock, or shut-in formation pressure, as a maximum, compresses the gas adjacent to the well into a smaller space than it formerly occupied. The same pressure that compresses the gas has but little effect on the volume occupied by the oil, as the oil has characteristics more like a pure liquid.

By holding the gas to a smaller volume, the oil occupies more of the space formerly occupied by the oil and the formation becomes resaturated. The resaturation has taken place under a declining flow differential, yet the production will be maintained and sometimes increased. The principal advantage gained is that of reducing the volume of gas produced per barrel of oil with assurance of a greater ultimate yield and lower production costs.

High back-pressures are conducive to steady flow and minimize clean-out costs. High rates of flow cause sanding up of wells, and the closing of the porosity near the well by fine sand and sediment carried along by the oil.

The Gas-lift

The gas-lift provides an excellent means of holding back-pressures on a formation. The pressure on the formation is governed by two factors. One is the oil head, H, between the bottom of the tubing and the top of the pay; the other is the working pressure of the input gas (Fig. 4). H is governed by the position of the tubing above the formation. The working pressure is governed by the size and length of the flow line and the relative amounts of oil and gas flowing.

When a well is equipped with a gas-lift during the time it will still flow naturally, the total pressure on the formation should be maintained at as high a point as possible. Small tubing for the flow line can be used to accomplish this or larger tubing with a choke or "bean" at the surface. Holding back-pressure on gas-lift wells is not generally practiced, but good results may be obtained by so doing. Fig. 5 shows the effect of placing a well on the gas-lift under pressure control by restricting the flow line at the surface.

The gas-lift provides a means of increasing the flow rate of most wells where applied and is generally installed for this purpose. Such practice, however, will not generally give the maximum ultimate recovery. Fig. 5 shows the production curve of a well that produced first under

natural flow with back-pressure, then on the gas-lift without pressure control and later by the gas-lift under pressure control.

The well declined under flowing conditions as shown during the first three months of its life. The dotted line drawn in is the estimated decline curve of the well under normal conditions. At the end of three months the well was placed on production by the gas-lift, and followed the decline shown. The dashed line is the estimated decline while the well was producing on the gas-lift. After two months on the gas-lift the well was placed on the gas-lift under pressure control at the surface

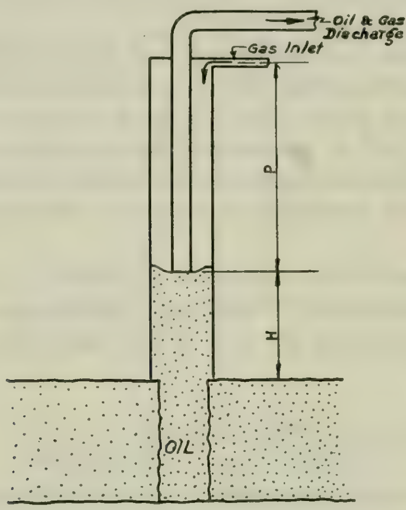


FIG. 4.—GAS-LIFT HOLDING BACK-PRESSURE ON FORMATION.

and from that time on for the next several months the decline practically stopped. This condition is realized on account of the highly saturated condition existing at the bottom of the hole and the minimizing of the differential between the formation and the well. Whether a well is being produced by the gas-lift or is flowing naturally, the effect on its ultimate production is controlled by the pressure conditions in the well.

When considered as a means of back-pressure control the gas-lift may be compared to natural flowing wells under back-pressure. The formation below the flow line is of first importance and is governed by the same factors as a natural flowing well. The flow in the tubing, which is a means of controlling the flow differential, has been given much detailed discussion and is given secondary importance in this discussion.

Fig. 6 shows data obtained by actual test on a natural flowing well.[3] An analysis of these data shows that as the flow bean opening is reduced

[3] Personal communication from K. C. Sclater.

the production rate is also reduced. The rate of decrease in production is about equal to the reduction in area of the opening through the flow bean. It can also be seen that as the flow bean size is decreased the amount of gas produced is very materially lessened up to a certain point.

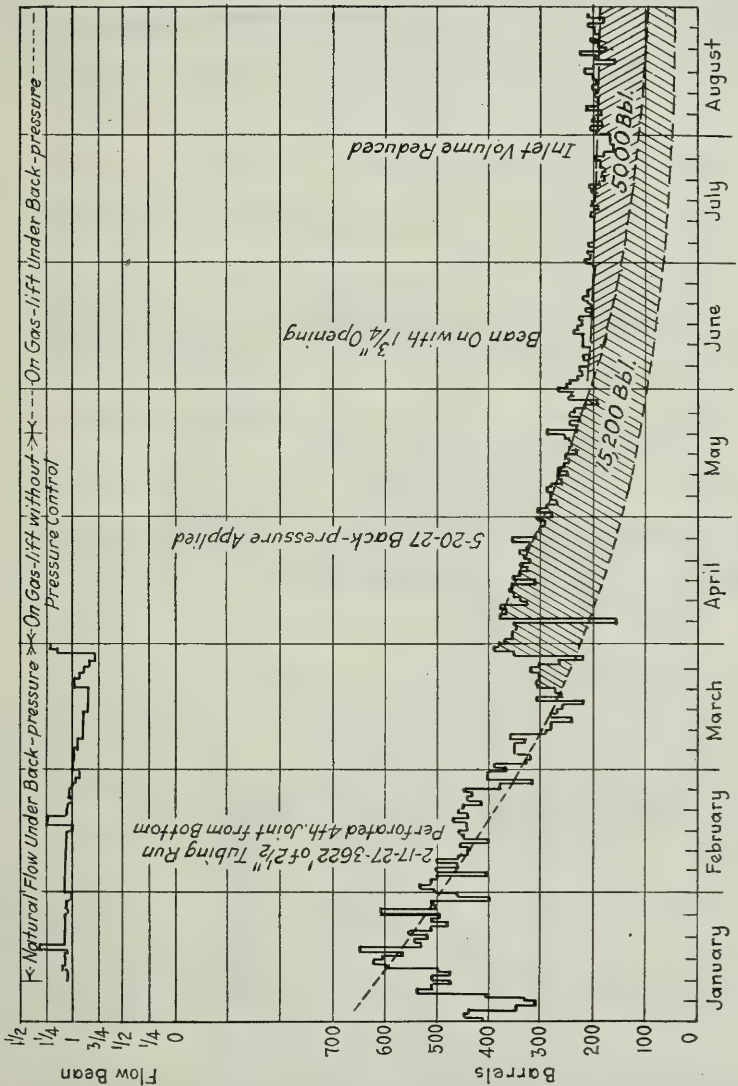


FIG. 5.—PRODUCTION CURVE OF WELL UNDER THREE DIFFERENT CONDITIONS OF OPERATION.

At this point the flow differential is such that the formation is practically resaturated, as previously mentioned. After this point is reached further reduction of bean size has little effect on the amount of gas escaping with the oil.

The lower curve of Fig. 6 is calculated from the gas and oil production curves. It clearly shows that there is a pressure at which the well can be operated to give maximum efficiency regarding the gas factor. This

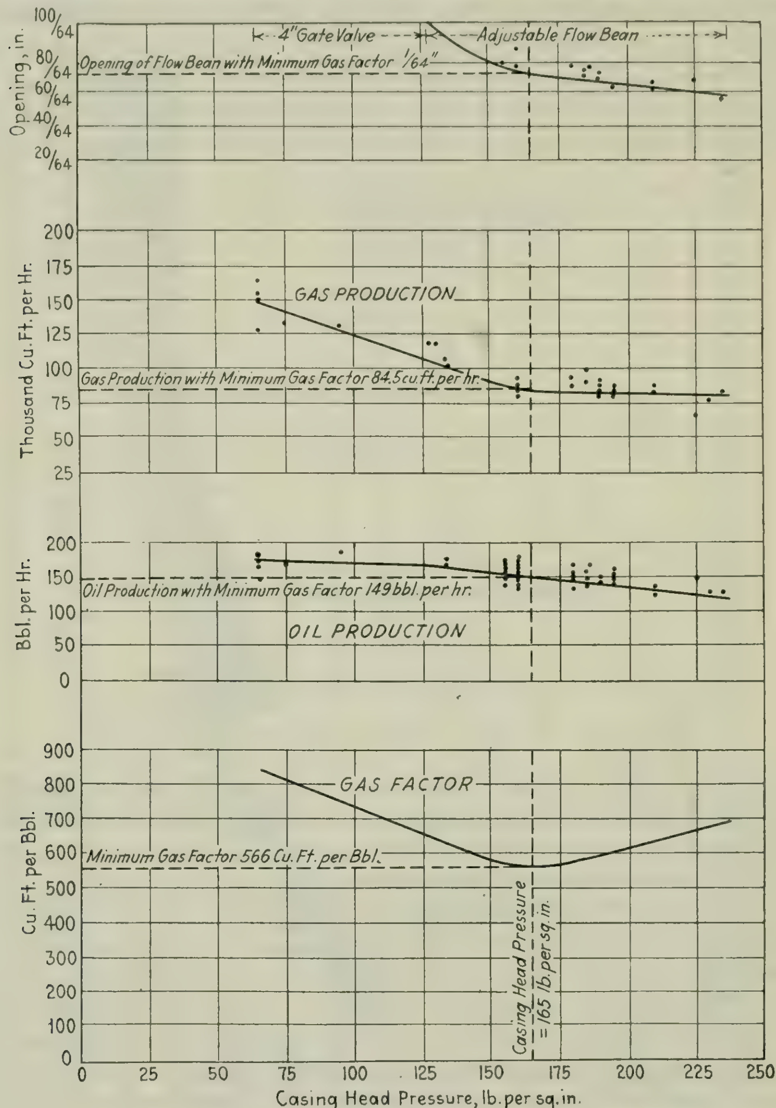


FIG. 6.—DATA OBTAINED BY ACTUAL TEST ON A NATURAL FLOWING WELL.

point may not give the best mechanical efficiency regarding the flow line, but it is the one that will allow the well to produce the greatest ultimate amount and the point at which the well should be operated regardless of flow-line efficiency.

As the formation gradually becomes depleted the pressure conditions change. This effect causes the low point of the gas-factor curve to move to the left. Not enough data have been obtained to date to indicate the relationship between the working pressure and the rock pressure for the point of minimum gas factor. It is, however, assumed that for any particular well there is a definite relationship and that the point of minimum gas factor can be calculated at any time from the rock-pressure

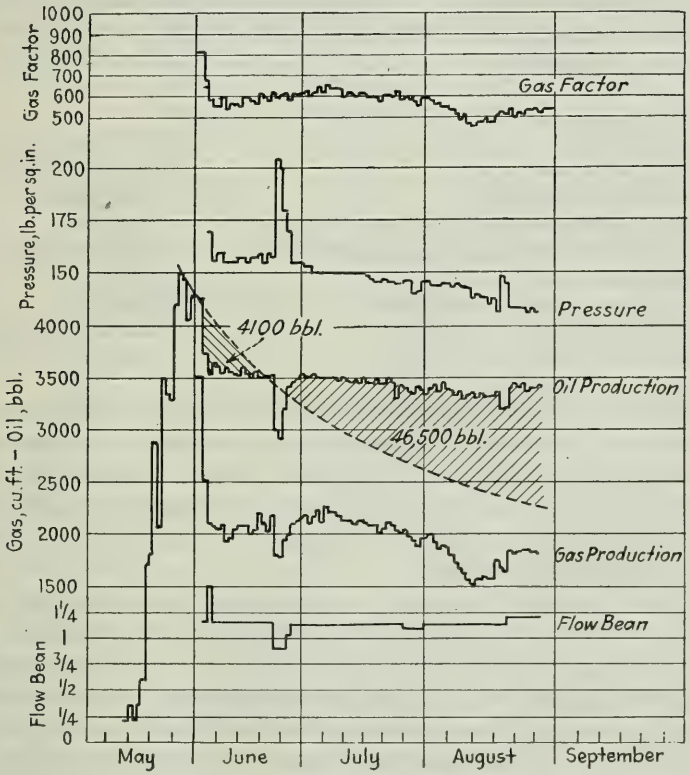


FIG. 7.—PRODUCTION CURVES OF WELL THAT FURNISHED DATA OF FIG. 6.

decline curve of the well. Work done on control and operation of gas wells shows that this relationship exists.[4]

When a well, either flowing naturally or by gas-lift, is put under pressure control, the production rate for best results is reduced to 60 to 80 per cent. of the open flow of the well. After the differential in the formation is decreased, due to the pressure imposed, the decline rate will be far less than that which will normally occur under open flow conditions. The amount of oil not produced after first applying back-pressure, on

[4] E. O. Bennett and H. R. Pierce: New Methods for the Control and Operation of Gas Wells. *Proc.* Natural Gas Assn. of Amer. (1925) **20,** 69.

account of the decreased rate, is soon regained by the flat decline existing after back-pressure is applied.

Fig. 7 shows the production curves of the same well from which the data of Fig. 6 were obtained. While the data obtained cover a period of a few months only, the results are typical of those to be obtained over long periods by pressure-control methods of operation. The curved line in the oil-production curve of Fig. 7 is a normal decline for wells in the vicinity of the one referred to. It can readily be seen that after 17 days from the time back-pressure was applied the decline curves crossed. A study of Fig. 7 shows:

Total oil produced from May 18, 1927 to Aug. 22, 1927	327,777 bbl.
Total gas produced	199,004 M. cu. ft.
Average total gas factor	612 cu. ft.
Oil produced before applying pressure control	53,194 bbl.
Gas produced before applying pressure control	42,118 M. cu. ft.
Average gas factor	812 cu. ft.
Oil produced under pressure control	274,583 bbl.
Gas produced under pressure control	156,886 M. cu. ft.
Average gas factor	569 cu. ft.

The pressure control is responsible for the reduction in gas factor from 812 to 569 cu. ft., or 243 cu. ft. for each barrel produced. At this rate the total amount of gas conserved by pressure control is 66,724 M. cu. ft. At 569 cu. ft. per bbl. this amount of gas is sufficient to produce 117,270 bbl. The cost of making this change in gas factor has been only the time required for making the study.

The total estimated increase in cumulative production to date is 42,400 bbl. The present daily open flow rate of the well is 3400 bbl. The pressure control rate is 2150 bbl., or 63.2 per cent. of the open flow rate.

The gas-lift, properly applied and controlled, will increase the ultimate production of a well. If not properly handled, it will decrease the ultimate production. Proper handling consists principally of the degree of skill practiced in maintaining back-pressure control on the formation.

Fig. 8 shows the production and gas-decline curves of a gas-lift well. The data for these curves were started the day the well was placed on the gas-lift. This well would not flow naturally when drilled in but was swabbed through the 8¼-in. casing at the rate of 1700 bbl. per day. Swabbing the well caused the collapse of the bull-wheel shaft and other difficulties accompanying this method of production, which made it uneconomical. The lowest possible back-pressure was imposed on the well while it was being swabbed.

After the well was placed on the gas-lift it declined regularly at the rate of about 6.5 bbl. per day, with an increasing natural gas factor and a declining working pressure. Although the decline on the gas-lift was far

less than that under natural flowing conditions, it was considered too great. The estimated natural-flow decline curve is shown below the gas-lift curve. After the well had produced for about two and one-half months, the tubing pattern was changed, which permitted a reduction in working

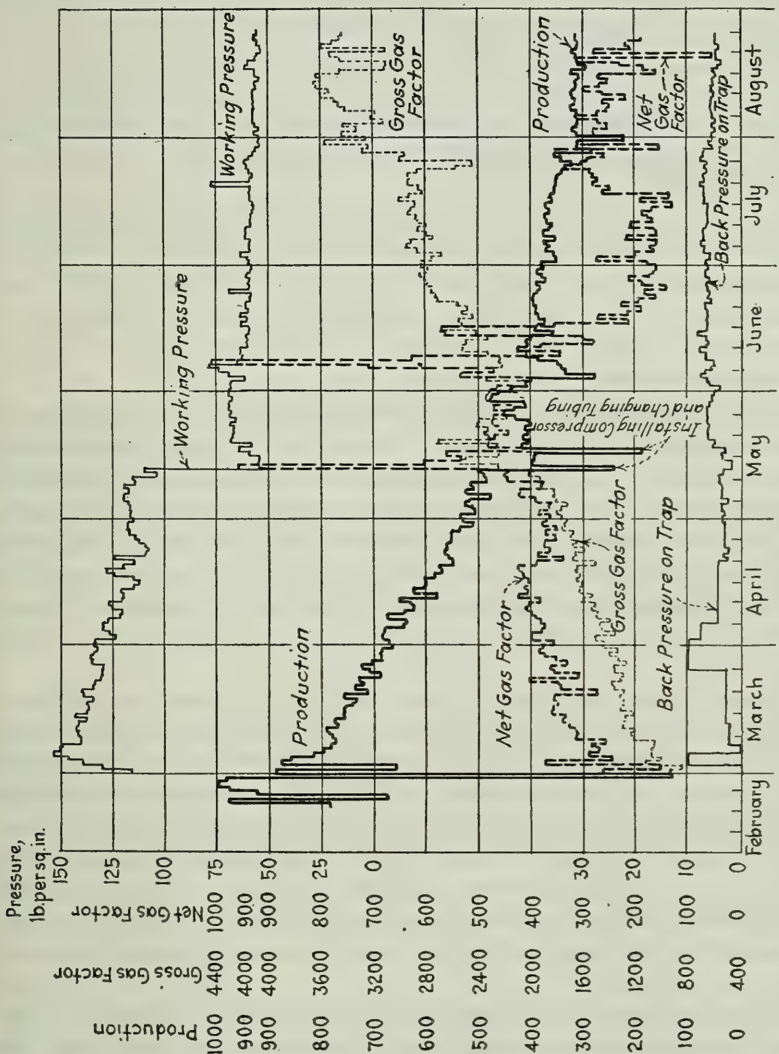


FIG. 8.—PRODUCTION AND GAS-DECLINE CURVES OF A GAS-LIFT WELL. Extreme irregularities are due to engine and compressor troubles.

pressure from 124 to 60 lb. This large reduction in pressure was made possible by circulating more gas per barrel than had been previously used. This can be seen by studying the gross gas-factor curve. At the same time that the pressure was reduced in the flow line, the back-pressure on the formation was reduced.

Based on mechanical efficiency in the flow line, as is general practice, the efficiency of this well looks exceedingly poor, the output gas factor being about 3500 cu. ft. per bbl. In making the changes, the net or natural gas factor was decreased from 500 to 175 cu. ft. per bbl. In other words, the change permitted the well to produce with about one-third as much energy as had previously been used from the formation. It will be noted that while the production rate dropped after the change was made, its rate of decline became much less, and in 12 days after the change was made the curve crossed the former decline curve and remained practically constant. Extreme irregularities in the curves are due to engine and compressor troubles.

The only expense involved in handling a well in this manner, as compared to getting maximum efficiency from the flow line, is the cost of compressing the gas circulated. When the production under "flow-line efficiency" is compared with that under "ultimate efficiency," it can be seen that this added expense is very small compared to the increased returns from production.

In this particular well, there was no increased cost on account of increased amount of gas circulated. When the tubing or flow line was changed to permit the larger volume, the working pressures changed to the point where single instead of two-stage compression could be used. This permitted handling a larger volume with the same horsepower requirements, the cost being proportional to the horsepower used. In designing a gas-lift installation, it is advisable to choose a type of machinery that can readily be changed from two-stage to single stage when required.

By maintaining some back-pressure on the well head, the efficiency of the whole cycle is increased. Maintaining 15 lb. on the compressor intake doubles its capacity. The increased capacity permits lifting the oil with higher back-pressure than could otherwise be used and with the well head back-pressure permits the total differential pressure from the formation to the trap to be controlled. The working differential in the well referred to is but 38 lb. from the sand to the trap. The depth of the well is 2500 ft. and the size of the flow line is $5\frac{3}{16}$ in. This is considerably larger than the flow lines used in general practice for wells producing but 300 bbl. per day.

By proper handling of the gas in a gas-lift cycle the gravity of the oil may be raised and the amount lost by outage vapors decreased. On the well referred to the discharge from the trap is recycled through the compressor. The wet vapors or lighter hydrocarbons that formerly escaped from the trap amounted to 5 per cent. of the total production; when returned through the closed system, they increased the production 20 bbl. and the gravity 3.75°.

The gas-lift can be very effectively used to increase the ultimate production of a field in which bottom-water encroachment is encountered. Pressure and flow conditions may be regulated so that back-pressures on the formation sufficient to hold down bottom water coming can be maintained allowing lateral drainage of oil above the water plane. This method of operation has been in successful use for the past year in the Panhandle. A well in this district, which made 100 per cent. water in December, 1926, has averaged 590 bbl. of oil per day since that time.[5] The gas-lift has also made economical recovery from wells producing as much as 90 per cent. water. Some wells in this class produce as much as 2500 bbl. of fluid with but 250 bbl. of oil. A pump cannot be made to handle this volume of fluid. However, large-capacity pumps set in the casing by slips and packers and operated without tubing are being used for pumping large quantities very successfully.

Cleaning Out Wells

Wells operating on the gas-lift seldom need cleaning out, because of the steady flow conditions that prevail. This fact has been instrumental in the development of a new and successful clean-out method, which involves the fundamental principles of the gas-lift. The new method makes it possible to clean out deep pumping wells in approximately 5 to 10 per cent. of the time previously required, with a saving of $1500 to $3000 per job. The information thus gained from the gas-lift has made it possible to increase the ultimate yield of pumping wells.

Conclusions

1. Where pressure conditions are suitable for using the gas-lift the flow rate of wells thus producing can generally be increased over the rate which can be maintained by other means.

2. When the gas-lift is used to increase the daily rate of a well, instead of being used as a means of back-pressure control, the ultimate production of a well will generally be decreased.

3. If the gas-lift is used as a means of controlling the pressure on the formation, the daily rate will be decreased but the well's ultimate production will be increased.

4. The gas-lift is effective in increasing the ultimate production of a field under hydrostatic pressure where water has encroached into the oil-bearing formation.

5. Where offset wells are producing on the gas-lift the best results and greatest ultimate recovery can be made when they are operated

[5] E. O. Bennett and K. C. Sclater: Some New Aspects of the Gas-lift. Petroleum Development and Technology in 1926, 115.

under similar conditions. An agreement as to pressure and rates should be reached by the operators. Trying to beat the offset generally works to the disadvantage of both.

6. To obtain the greatest ultimate yield from a well complete knowledge of pressures and volumes must be obtained. Proper equipment and supervision is the only way in which this can be done.

[For discussion of this paper see page 182.]

Relation of the Air-gas Lift to Gas-oil Ratios and Effect on Ultimate Production

By F. W. Lake,* Brea, Calif.

(Fort Worth Meeting, October, 1927)

The ultimate production from a natural reservoir of petroleum is inversely proportional to the gas-oil ratios existing during the producing life of the reservoir whenever gas is the major expulsive force in the recovery. In other words, in the period during which gas is the major expulsive force the ultimate production will be increased if the gas-oil ratio is decreased, and vice versa. This condition prevails in the greater number of the present producing districts.

While this relation is difficult to prove from actual operation, on account of the present paucity of detailed observations, it must be admitted after a study of the forces and conditions governing the recovery of petroleum from natural reservoirs. Where gas and oil exist under pressure in sand interstices and water movement is not freely possible, the force expended in moving the oil to the well is the expansion and movement of the gas through the pressure differential existing between the interior of the reservoir and the well. If pressure and solution conditions in the untapped reservoir are such that the relation between gas and oil volumes at atmospheric conditions is as 100:1; and if during the producing period, until the gas is exhausted, the relation between the gas and oil volumes produced is 300:1, it follows that only one-third of the oil has been produced and the remaining two-thirds cannot be recovered unless some extraneous force is introduced into the reservoir. This serves to illustrate the importance of gas-oil ratio control during normal producing operations.

Gas-oil Ratio Control

Eliminating natural conditions in a reservoir, which govern gas-oil ratios, such as the physical properties of the oil and gas, the physical characteristics of the reservoir strata and the original pressure and solution conditions in the reservoir, which cannot be controlled by operation practice; and also eliminating operating conditions that apply to the reservoir as a whole, such as well spacing, well locations, relative completion dates, various penetrations and drilling practice; there remains but one condition in each well that influences the gas-oil ratio and that is

* Superintendent of Production, Union Oil Co. of California.

subject to control by operation practice—namely, the effective back-pressure existing in the well opposite each of the producing strata. For each well, at a certain time in its life there is an effective back-pressure that will give the minimum gas-oil ratio, but this effective back-pressure may or may not be within the limits determined by the various mechanical and economical conditions of actual practice. The minimum gas-oil ratio varies widely in different wells, in different areas, in different producing horizons and in the same well at various periods during its producing life. The minimum gas-oil ratio obtainable may vary from a few cubic feet per barrel to several thousand cubic feet per barrel, and in each case be a minimum for a certain well at a certain time.

Since gas-oil ratio control for each well lies in the effective back-pressure opposite each of the strata contributing to production, the various methods of production are more or less flexible in furnishing means for changing the effective back-pressure to obtain the minimum gas-oil ratio. In flowing wells it is usually difficult to change tubing diameters and depths and hence two factors remain for the adjustment of the effective back-pressure: (1) the regulation of back-pressure at the tubing head by beans, flow nipples or trap pressure and (2) the introduction of various amounts of gas in the casinghead similar to gas-lift practice. In pumping wells, the pumping depth, rate of pumping and the pressure held on the casinghead furnish means for the variation of the effective back-pressure to obtain a minimum gas-oil ratio. In gas-lift wells, however, more conditions that may be varied to obtain the effective back-pressure resulting in the minimum gas-oil ratio are introduced than in any other method of production. It is due to this characteristic of gas-lift operation that lower gas-oil ratios can usually be obtained, because the limits of effective back-pressure variation, which are controlled by the mechanical conditions of actual practice, are considerably extended.

In gas-lift operation, there are four convenient means for the control of the effective back-pressure. Adjustments in tubing diameters, tubing depths, gas volumes circulated and tubinghead pressures will permit considerable variation in the effective back-pressure. Fig. 1 illustrates conditions in the average gas-lift well. Gas is introduced between the tubing and the oil string at A, passing down between the tubing and oil string to the bottom of the tubing C and the oil and gas flowing up the inside of the tubing to the surface E. The casinghead pressure at A, less the pressure drop due to the friction of the gas flowing from A to B, and plus the static head of the gas from A to B, is equal to the pressure at B which is the effective back-pressure at the top of the first oil sand. The pressure at B, less the pressure drop due to the friction of the gas flowing from B to C and less the pressure drop due to the friction of the oil entering from the first oil sand and flowing from B to C, and plus the static head of the oil and gas from B to C, is equal to the pressure at C. The pressure

at C is also equal to the pressure drop due to the friction of the oil and gas flowing from C to E, plus the static head of the oil and gas from C to E and plus the tubinghead pressure at E due to flow nipples, beans or trap pressure. The pressure at C plus the pressure drop due to friction of the

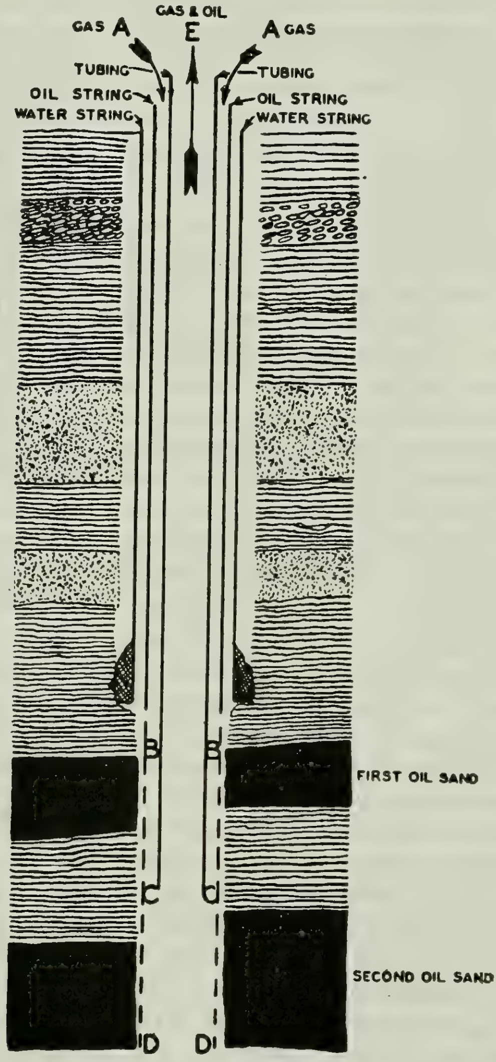


FIG. 1.—CONDITIONS IN THE AVERAGE GAS-LIFT WELL.

oil and gas entering from the second oil sand and flowing from D to C and plus the static head of the oil and gas from C to D is equal to the pressure at D, which is the effective back-pressure at the bottom of the well. This pressure cycle can be varied within certain limits to increase or decrease

the effective back-pressure on the first oil sand and at the same time either decrease or increase the effective back-pressure on the second oil sand by adjustments in tubing diameter, depth, gas volume circulated and tubinghead pressure. Thus the flexibility of effective back-pressure control in gas-lift operation is largely responsible for the means of obtaining lower gas-oil ratios than possible under other methods of operation.

Gas-oil Ratios Obtainable with Gas-lift Operation in Southern California Wells

Brooks Well No. 2 (Fig. 2).—In the beginning of 1925, this well was on the pump, producing between 180 and 200 bbl. per day. The production was declining while the gas-oil ratio was increasing more rapidly each month. In June, 1925, a two-weeks test was made on the gas-lift. The production was substantially increased and the gas-oil ratio decreased. After two weeks the well was put back on the pump, up to the first of September, 1925. The pumping production during this time, while less than that obtained during the gas-lift test, was considerably more than the earlier pumping record, and the gas-oil ratio, while higher than the gas-lift ratio, was lower than the former pumping ratio but was again increasing each month. When put back on the gas-lift permanently in September, 1925, the gas-oil ratio increased with the increase in oil production but remained lower than during the first pumping period. Up to June, 1926, the well was being flowed through 2½-in. tubing at a depth of 3800 ft. On June 1, 1926, the tubing was pulled and the well was flowed through the 6¼-in. oil string with the top of the perforations at 3470 ft., the gas being introduced between the 6¼-in. and the 8¼-in. With this change, the oil production almost doubled the previous gas-lift production but the gas-oil ratio showed a tendency to increase rapidly. The increase in the gas-oil ratio was stopped by decreasing the amount of gas circulated until the latter part of 1926. The encroachment of water into the well began increasing rapidly until the well was producing 30 per cent. water and the amount of gas introduced into the well had to be gradually increased in order to handle the increasing water production. The gas-oil ratio indicated a tendency to rise as long as the gas introduced into the well was increased. In June, 1927, a large portion of the water production was eliminated and the gas introduced into the well was decreased with a corresponding decrease in the gas-oil ratio. The drop in casinghead pressure in June, 1926, with the corresponding gas and oil increases, indicated a decrease in the effective back-pressure throughout the producing horizon, which increased the gas-oil ratio temporarily. However, by continuing the decrease in the effective back-pressure by decreasing the gas volume circulated until the end of 1926, the gas-oil ratio was again decreased. From the end of 1926 to the middle of 1927, the gradual increase in effective back-pressure was accompanied by an

increase in the gas-oil ratio. During the last two months the decrease in the effective back-pressure has been accompanied by a decrease in the gas-oil ratio. A change in the relationship between effective back-pressure and gas-oil ratio during 1926 and 1927 is indicated. This curve illustrates the close relationship existing between gas circulated and gas-oil ratio.

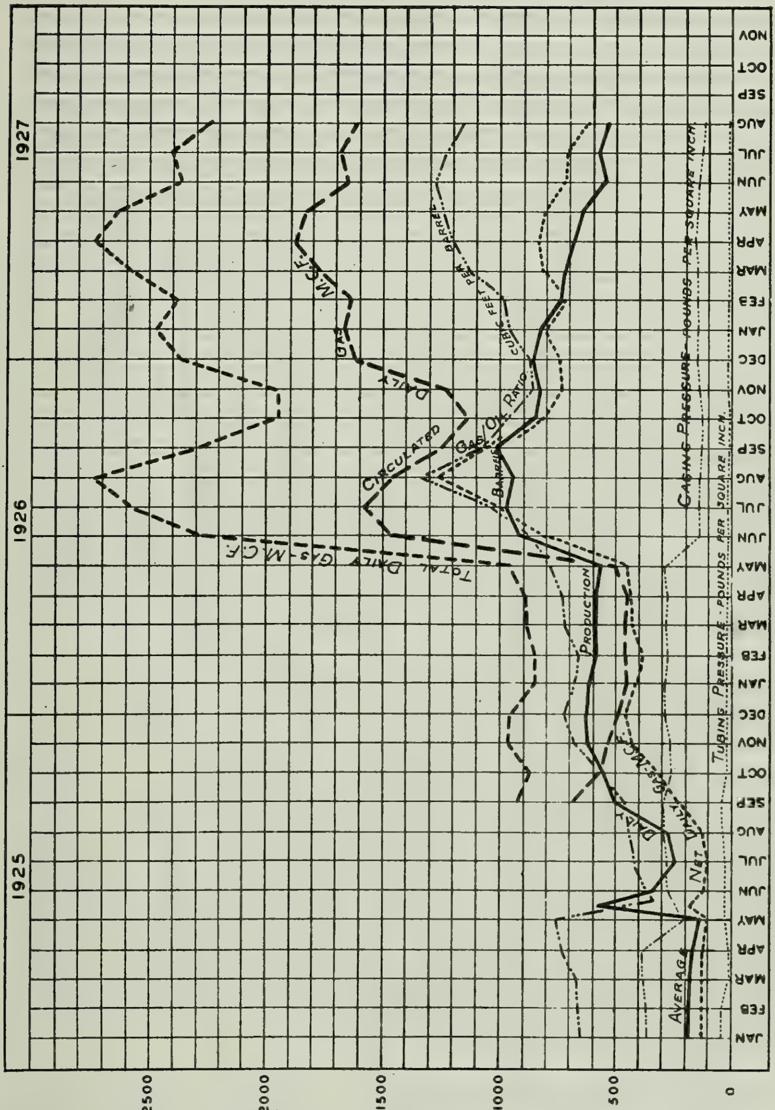


FIG. 2.—PRODUCTION CURVE, BROOKS WELL No. 2.

Chapman Well No. 7.—During 1925, this well was pumping less than 200 bbl. per day with the production remaining almost constant. The gas-oil ratio declined until the last two months in the year when it

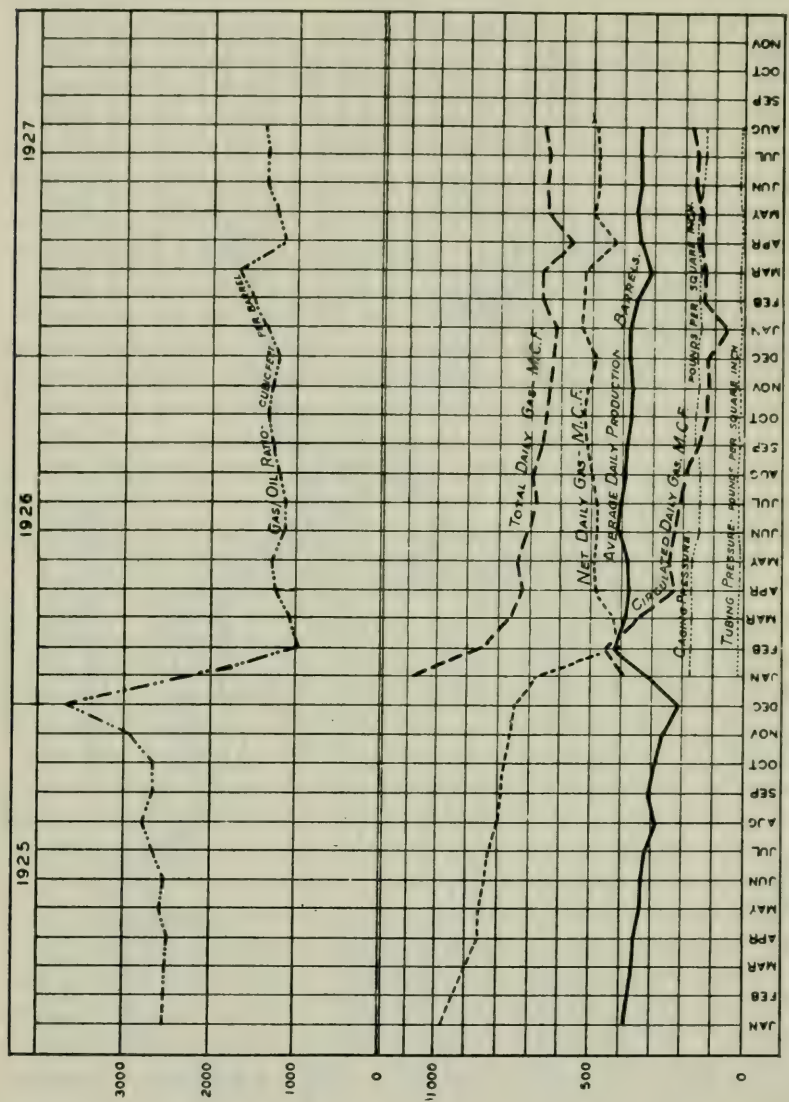


FIG. 3.—Production curve, Chapman Well No. 19.

increased rapidly. In February, 1926, the well was put on the gas-lift with a substantial increase in production. The gas-oil ratio was increased to more than double. By increasing the volume of gas delivered to the well, it was found that the gas-oil ratio decreased until it was lower than

the previous pumping ratio. During 1926, the relation existing between the effective back-pressure and the gas-oil ratio was such that the gas circulated and the gas-oil ratio were inversely proportional to each other. In the first part of 1927, however, with the gas circulated remaining almost constant, the gas-oil ratio decreased. A change in the relation between gas circulated and gas-oil ratio was taking place, so that from May to July, 1927, within the same numerical limits as before, the gas circulated and gas-oil ratio were then directly proportional to each other. With no changes in operation other than gas volumes circulated, the relationship existing between gas circulated and gas-oil ratio has been directly reversed during two years.

Chapman Well No. 19 (Fig. 3).—In the first part of 1925, this well was flowing about 390 bbl. per day with a gas-oil ratio of 2550 cu. ft. per bbl. The decline in production was normal throughout 1925 with an increase in the gas-oil ratio until in December. The well started to flow intermittently and the gas-oil ratio increased to 3650 cu. ft. per bbl. with the oil production averaging 200 bbl. daily. The well was then placed on the gas-lift with a decrease in the gas-oil ratio to 1000 cu. ft. per bbl., with an increase in production to 415 bbl. daily. Since that time, the oil production has declined slowly, the gas production remained about the same and the gas-oil ratio gradually increased. While on the gas-lift, the gas volume circulated was slowly decreased to the first part of 1927 and since then has been gradually increased. During the last few months of 1927, the gas-oil ratio has shown little change, remaining under 1400 cu. ft. per barrel.

Chapman Well No. 25 (Fig. 4).—This well was completed in October, 1926, and pumped for the balance of the month. The production averaged 190 bbl. with a gas-oil ratio of 1670 cu. ft. per bbl. In November, it was placed on the gas-lift, increasing the production four times and decreasing the gas-oil ratio by one-half. Since that time, there has been a normal decline in the production accompanied by an increase in the gas-oil ratio. During this period, the gas volume delivered to the well has been decreased every month so that in the 10 months that it has been on the gas-lift, the gas volume introduced has dropped from 2600 m. c. f. to 800 m. c. f. daily with no changes in operation except a definite decrease in the gas volume circulated. The gas-oil ratio has continued to increase but is still at a much lower point than the ratio obtained during the pumping operation.

Coyle and Bogue Well No. 3.—During the first part of 1925, this well was still flowing about 250 bbl. per day with a gas-oil ratio of about 1600 cu. ft. per bbl. During May, the production started to decline rapidly as the well commenced flowing by heads and the gas-oil ratio increased very rapidly, so that by July the production had dropped to 110 bbl. daily with a gas-oil ratio of 4700 cu. ft. per bbl. At this time, the well

was placed on the gas-lift with an increase in production and a very pronounced decrease in the gas-oil ratio. While on the gas-lift, there has been a normal decline in production accompanied by an increase in the gas-oil ratio, but the gas production from the formation has remained practically constant and at the same point as that produced while originally flowing. This well is peculiar in that there is a gas sand lying just below the water shut-off and the volume produced from this sand is

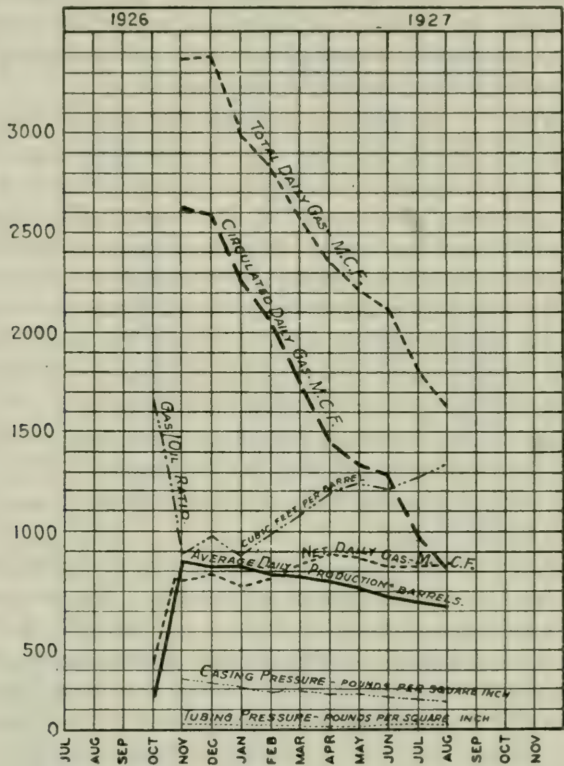


FIG. 4.—PRODUCTION CURVE, CHAPMAN WELL NO. 25.

apparently more or less constant irrespective of the various changes in gas circulated, tubing depth or other adjustments made on the well. For this reason, the apparent gas-oil ratio has steadily increased as the well's production declined.

Morse Well No. 3 (Fig. 5).—In the first part of 1925, this well was flowing naturally and starting to head. The gas-oil ratio increased to 2500 cu. ft. per bbl. but was then decreased to an average of 1500 cu. ft. per bbl. by beaning the well until August, 1925. At this time, the well was placed on the gas-lift and the production increased about four times. The gas-oil ratio was decreased by more than one-half. In the initial

gas-lift operations, the gas-oil ratio increased steadily until adjustments were made removing all pressure possible from the tubinghead and decreasing the gas volume circulated. From the middle of 1926 to the

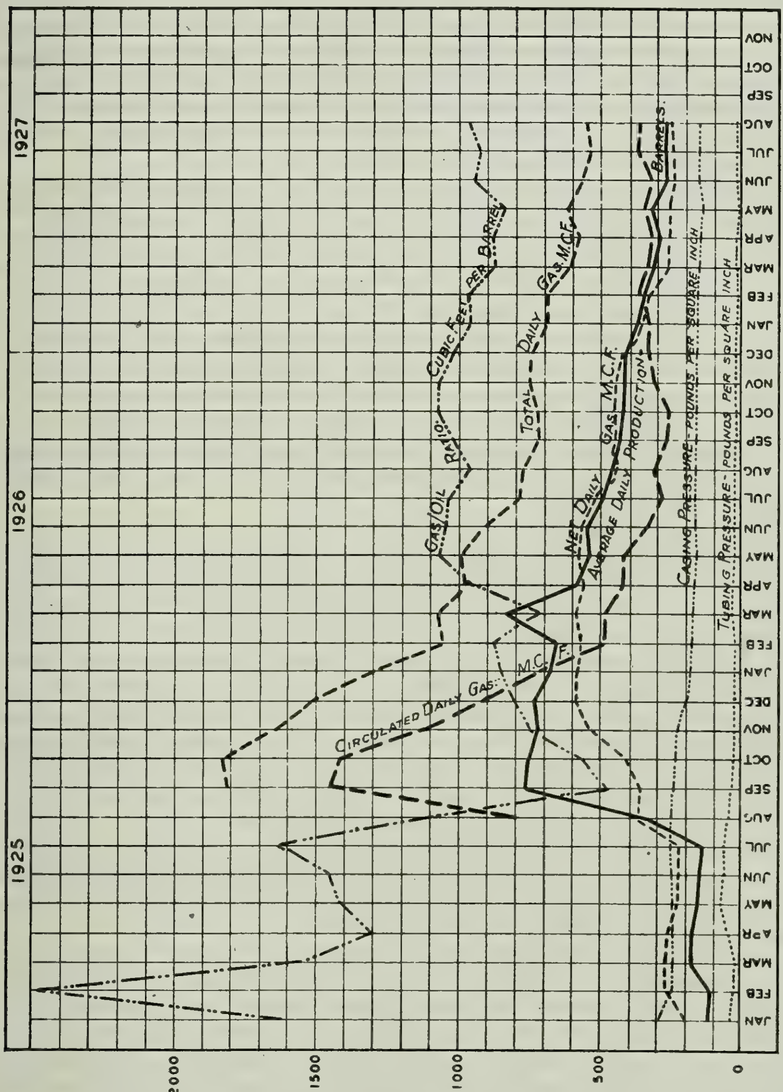


Fig. 5.—Production curve, Morse Well No. 3.

present time, the oil production has declined while the gas-oil ratio has shown a tendency to decline. This curve serves to illustrate the relation between tubinghead pressure, casing pressure and gas volume circulated in their relation to the gas-oil ratio with the tubing diameter and depth remaining the same.

DISCUSSION

[Includes also discussion of paper by E. O. Bennet pages 158 *to* 172]

W. P. Haseman,* Ponca City, Okla.—The natural gas in an undisturbed natural petroleum reservoir is present in two forms—in the gaseous phase above or separated from the petroleum, and as dissolved gas in the liquid phase throughout the petroleum. Both forms must be reckoned with in the study and efficient application of production technique and methods. When a well penetrates a reservoir, petroleum and gas begin to flow through the formation toward the well as a point of released pressure. This flow is accompanied by a progressive pressure drop as the fluid acquires increased velocity and friction in the formation is overcome.

An alteration in the pressure confining natural gas in a petroleum reservoir will alter the natural gas present in both phases. When the pressure is increased, the natural gas will be compressed and part of it will change into the liquid phase. This altered condition results in energy being stored in the fluids because work must be done to bring about the changed condition. On the other hand, when the pressure confining the gas in the petroleum reservoir is decreased, that in the gaseous phase will expand and that in the liquid phase will come out of the petroleum and its volume will increase many times as its phase is changed. This altered condition results in a liberation of energy, and work is done by the gas expanding in increasing the velocity of the fluids and overcoming friction in the formation as the fluids flow toward the well. The quantity of energy stored in any given volume of the petroleum depends on the quantity and nature of the component parts of the petroleum fluids present, their temperature and pressure.

This stored energy in a petroleum reservoir as a result of pressure on the natural gas is of paramount importance in most oil fields in the natural production of petroleum. It is through this energy that the natural gas becomes the prime "motive force" which moves the petroleum fluids through the reservoir formation into and out of the well by natural flow. It is analogous to that stored in the water, steam and air in a heated boiler. In fact, the reservoir with its petroleum liquid, hydrocarbon vapors and gases may be likened in every respect to a heated boiler filled with water, steam and air. It is a familiar fact that as the reservoir boiler is heated, the temperature of the water is raised and steam is formed, with a resulting increase of pressure in the contained water, steam and air. This increase of pressure indicates that an increased amount of energy is stored in the fluids. Similarly, there is energy stored in the petroleum fluids contained in a natural reservoir. The reservoir has a fixed earth temperature determined largely by its depth. It is above the boiling point of several of the hydrocarbons which constitute a part of the liquid volume contained in the reservoir. In addition, the hydrocarbon vapors and gases existing as such in the reservoir are compressed.

It is well known that if a boiler containing water, steam and air at high pressure and at a temperature considerably above boiling water is tapped by drilling a small hole through the top, some of the air and steam is expelled with very little, if any, of the water as liquid. However, if the opening were very large the air and steam would be expelled with such violence and in such quantities as to approach an explosion, and in that event considerable water might be expelled. Again if the boiler were packed with sand and the pore space filled with water, steam and air, the outflow when tapped would be quite analogous to the flow of petroleum, hydrocarbon vapors and gases from the reservoir into the well. It would appear that in case the bore of a well that taps the petroleum reservoir were sufficiently small to restrict the more or less free flow of the petroleum fluids into the well, the natural flow would be largely vapors and gases which distil from and move through the petroleum liquid in such form and with such velocity to the well as not to trap and expel an appreciable

* Marland Oil Co.

quantity of petroleum. Should the bore of the well become large enough, the wells be drilled sufficiently close to each other and all opened to flow simultaneously, the expulsion would approximate an explosion and the greatest possible amount of the petroleum fluids would be expelled. In this, of course, the reservoir conditions are assumed to be homogeneous, particularly with reference to the conditions affecting the factors that control the rate of flow of petroleum.

The problem of the flow of the petroleum fluids through the reservoir formation is considered very difficult to formulate and more difficult to solve. Notwithstanding this, if an oil well be considered as a source of potential energy, hypothetical problems can be formulated and solutions secured that represent the observed facts very well.

To get a qualitative picture of the flow of the petroleum fluids through a natural reservoir, let it be assumed that the reservoir formation consists of three sections, each with a definite but different permeability, so that in the uppermost section under existing conditions the contained fluids would move toward the well with a velocity V_1; the central section supports a velocity V_2; the lowest section, a velocity V_3. It is further assumed that the central section is the most permeable, the uppermost next and the lowest least permeable, so that V_2 is greater than V_1 and V_1 is greater than V_3. Let it be assumed that initially the undisturbed reservoir had a fluid with constant gas-oil ratio throughout.

Now suppose that a well is drilled into the reservoir and a movement of the fluids starts toward the well with a progressive drop in pressure. Since the speed through the central section is considerably greater than through the upper and lower sections, the corresponding pressure drops in the three sections will tend to be different, the greatest being in the central section. This condition cannot exist if any fluid, particularly gas and vapor, can distil across from the boundary of one section to another in appreciable quantities. The result is that gases and vapors in the uppermost and lowest sections will continually distil across into the central section, thus materially increasing its gas-oil ratio. The case may be further simplified for discussion by assuming that the permeabilities of the uppermost and lowest sections are such as to prevent the flow of the petroleum fluids, particularly the liquids, through the sections to the well. This will limit the petroleum production to the central section and might represent actual conditions in the late life of a well. Thus, as the petroleum in the central section is moved along toward the well, vapors and gases will be added to it from the other sections. Obviously, the petroleum farthest from the well will, as it flows to the well, receive more gas and vapor than an equal amount closer to the well. The gas-oil ratio of the petroleum production, therefore, will increase with the life of a well.

In principle the same result will take place in a fairly homogeneous reservoir formation, since certain of the winding pore openings as channels have on an average larger and more uniform cross-section than the majority of the channels. These larger and more uniform ones will carry a fluid with a greater speed and a greater gas-oil ratio than the other channels. This ratio will be augmented with time in free flow by distillation from neighboring channels. Natural gas is endeavoring to escape from the reservoir in such a way as to reduce the energy stored in the reservoir to a minimum without storing up or transferring any part of it to matter in another position or phase. The natural gas, therefore, attempts to clear the petroleum from the larger and more uniform pore channels, which, when cleared, will permit the free egress of the residual natural gas from the formation to and out of the well, leaving a maximum of the petroleum in the reservoir. This accords with a fundamental scientific energy principle and to fulfill it under the existing reservoir conditions the gas-oil ratio must increase as the petroleum production declines. Accordingly, a retardation in the speed of the free flow in the larger and more uniform pore channels relative to that in other neighboring channels would reduce the rate of distillation

into the larger channels and therefore reduce the gas-oil ratio until a minimum condition is reached.

W. S. MORRIS,* Seminole, Okla.—Mr. Millikan stated, if I understood correctly, that he had been able to produce some of his wells at Seminole with a lower formation gas-oil ratio on the gas-lift than he obtained when the wells were flowing naturally. Our records of the Seminole wells indicate that on the average the formation gas-oil ratios are considerably higher on the gas-lift than when the wells were flowing naturally, and that the lowest formation gas-oil ratios were obtained shortly after the wells came in—during their flush initial production. Some engineers, however, claim that pumping is the most efficient, gas-lift less efficient, and natural flow the least efficient. This is perhaps true in general.

The method of determining the efficiencies would have to be known to make comparisons intelligently of data from different sources. It has been clearly shown that figures representing merely the number of cubic feet of gas (probably measured at atmospheric pressure) produced per barrel of oil is not an absolute index of efficiency.

The data available on gas-oil ratios at Seminole, both natural flow and gas-lift, are perhaps subject to correction, on account of several factors. For instance, on the gas-lift, the input gas may be measured with an orifice meter while the output gas from the trap may be measured two or three times a day with a Pitot tube. I am not saying that the Pitot tube, in the hands of a skillfull operator, is not as efficient a measuring device as the orifice meter, but I do challenge the accuracy of the volumes thus derived from intermittent observations, and their consequent comparison with the results of recording orifice meters.

It has also been my observation that sufficient importance has not been attached to temperature, pressure, and gravity corrections of the air or gas in the measurement of these media for air-lift and gas-lift work. For instance, suppose we have a 1-in. orifice in a 2-in. standard pipe line and assume that the gravity of the gas is 1 and that the base and flowing temperature is 60° F., with a pressure base of 0 oz. From the handbook,[1] we find the coefficient for flange pressure connection to be 211.88.

If the temperature of the gas were actually measured at the meter and found to be 120° F., the following correction should be máde:[2]

$$\text{Multiplier} = \frac{460 + \text{New Base Temperature}}{460 + \text{Base Temperature of Coeff. to be revised}}.$$

$$\text{Multiplier} = \frac{460 + 120°}{460 + 60°} = \frac{580}{520} = 1.1154$$

If the gravity of the gas were taken at the meter also, and found to be part air and part gas with a gravity of 0.70 instead of 1.00 as we assumed, the correction factor would then be:[3]

$$\text{Multiplier} = \sqrt{\frac{\text{Spec. Grav. of Coeff. to be revised}}{\text{Actual Specific Gravity}}}$$

$$\text{Multiplier} = \sqrt{\frac{1.00}{0.70}} = 1.1952$$

Applying these corrections to the observed coefficient of 211.88, we have

211.88 × 1.1154 (Temp. Correction) = 236.33095
236.33 × 1.1952 (Grav. Correction) = 282.46162
Final Observed
282.46 − 211.88 = 70.58
70.58 ÷ 211.88 = 0.333113 or 33⅓ per cent.

* U. S. Bureau of Mines.

[1] Orifice Meters, 44. Metric Metal Works, Erie, Pa.

[2,3] *Op. cit.*, 51.

Thus our calculated volumes, with our assumed temperature and gravity, would be 33⅓ per cent. low, and consequently our calculated gas-oil ratios would be correspondingly low.

Thus far no correction for pressure has been made, yet we know that there are variations of Boyle's law: $PV = RT$. Van der Waal's equation for this correction is as follows:[4]

$$\left(P + \frac{a}{V^2}\right)(V - b) = RT$$

where a = constant
b = volume of molecules
V = volume

The compressibility factors for several gases are shown graphically by curves in a circular of the Bureau of Standards.[5] From the curve for the compressibility factors for air (page 14) it is observed that at 20 atmospheres (absolute) and 50° C. (122° F.) the factor is 0.99875, while the factor for methane (page 18) is about 0.977. These correcting factors due to pressure are small and will not be used in calculating the volumes.

From observations, it would seem that no common basis has been agreed upon whereby we may intelligently compare formation gas-oil ratios.

The lack of accurate data on gas measurements in gas-lift work, particularly, is a serious handicap in the attempt to study and apply the principles of the lift.

E. O. Bennett.—I do not think that the Pitot tube can be counted on being better than 10 to 20 per cent. off.

C. V. Millikan,* Tulsa, Okla.—We are using Pitot tubes for measuring the large volumes where extra large pipe would have to be installed in order to use an orifice meter. Most of the smaller volumes are measured with an orifice plate. Wherever the Pitot tube and orifice measurements have been compared, they have checked reasonably well. Although the accuracy of the Pitot is questionable, if it has not been standardized, the relative volume is correct, and this is the important consideration for the individual well. Correction is always made for temperature and gravity.

E. O. Bennett.—Did you use a standardized Pitot tube table for this?

C. V. Millikan.—We did not; we checked against orifice plates.

E. O. Bennett.—In figuring gas-oil ratios on high-pressure fields, we know the wet gases can deviate at 500 lb. as much as 5 per cent. We calculate our gas-oil ratios at atmospheric pressure; that is, we are getting lower formational gas-oil ratios. We may be in error at least 25 per cent. at the start. You will have more gas at that high pressure than you indicated you had.

A. G. Heggem, Tulsa, Okla.—I have been sitting here somewhat in the position of an unofficial observer, but there are some things that have come to my attention about which I should like to speak.

There seems to be a slight misunderstanding as to the duties of an engineer. There is a tendency for any art to get too technical and forget its real purpose in

---

* Amerada Petroleum Corpn.

[4] G. Senter: Outlines of Physical Chemistry, 25–35. New York. D. Van Nostrand Co., 1913.

[5] Relations between the Temperature, Pressures and Densities of Gases. *Circular* No. 279, U. S. Bureau of Standards (1926).

following the butterflies of technique. The thing that has impressed me during these meetings is the lack of complete data. I saw the charts and certain points, but cannot see anything to correlate these data so that anything can be projected. Until a smooth curve can be obtained, nothing can be projected. A series of lines means nothing without complete data. When you know that which you are now seeking to know your points will lie in a smooth curve.

Taking the facts and seeking the hidden elements, is there a relationship between porosity of sands, rock pressure, thickness of sands, size of casing, viscosity of oil and various other properties that can be determined? Is there anything in temperature? While you say, "We try 400 lb. and get a certain result, then we try 200 lb. and get a certain answer," what result do you get at 330? Why jump from 400 to 200; and is there some different result in between? If we want our data to be of use, let's get our facts so that when we apply them they will correlate with the other fellow's facts.

E. V. Foran,* Fort Worth, Texas.—Our information is confined to individual wells with respect to the relation of the gas-oil ratio to ultimate production. In any sand there is a certain volume of gas and oil; its nature of distribution we cannot be sure of yet. In the Salt Creek field in 1922 and 1923, the field was so prolific that meters, etc., were not completely installed at the time the drill touched the sand in many cases.

I had the opportunity during those years to get the natural ratios in the sand immediately after the drill touched the sand in many cases. I was surprised to find that at the end of 24 hr. the natural gas-oil ratio is less than half of what it is in 48 hr., whether in a small or a large well.

In tight-sand wells, the ratio rose rapidly over what it was in the loose-sand wells. If we waited 30 or 60 days afterward to get our information, we might be led to believe in an even distribution in the sand. The natural ratios confirmed this in nearly every case, and if we compare this to the well 12 months later, it increased 20 to 30 per cent. the maximum recovery from the sand.

In the deep sand, the ratios were extremely low and the gasoline content of the gas very high, by reason of saturation. I understand that the gasoline content is now somewhat leaner and the ratio is now three or four times what it was then.

Very little work has been done on the determination of the natural gas-oil ratio. When we get measurements as soon as the well is drilled in and finally produce 98 per cent. of the gas, we will have exact information and will know exactly how much oil is in the sand, if we know the true gas-oil natural ratio to each sand. Sometimes when wells are drilled in there is some free gas. Where the dissolved gas is more or less uniformly distributed the natural gas-oil determinations are valuable to us.

K. B. Nowels,† Laramie, Wyo.—I was particularly interested in Mr. Foran's remarks, as they bring us back to the discussion on three papers mentioned previously.

Mr. Foran is correct to a certain extent in the statement he made concerning the immediate increase of gas-oil ratios in flowing wells. My investigation in the Salt Creek field showed that in most cases in flowing wells there was a lower gas-oil ratio at the beginning than at the expiration of a test. The tests performed lasted from 5 to 20 days. The Salt Creek work seems to indicate the existence of a well defined maxim which says, "A flowing well, no matter how it is produced, continually trends toward inefficiency." This must be true to account for an increase of ratio with the age of the field, where gas is the propulsive medium.

---

* Production Engineer, Marland Oil Co. of Texas.

† U. S. Bureau of Mines.

Going back to Professor Uren's paper: There was some statement made to the effect that the gas-oil ratio is not a true factor in measuring well efficiency. I agree with him that if it were possible in every case to secure accurate data on formation pressures and temperatures, well efficiency could be expressed better in an engineering way in terms of foot-pounds of work done. However, there are few pressure data, and therefore the most convenient term is "gas-oil ratio." In my estimation, we are more likely to get into difficulties trying to base efficiency on foot-pounds of work done without accurate formation pressures, or a knowledge of the type of expansion which takes place, than we are by using gas-oil ratios. The common practice, as evidenced by some articles appearing in the trade journals, is to guess at the rock pressure and assume the expansion in a well as isothermal, when it is not.

The operator in the field wants to judge the efficiency of a certain method of producing a well by knowing whether he is decreasing the amount of gas accompanying each barrel of oil. This comparison is naturally made with some other way in which he has produced that same well. Usually the comparison is made with the gas-oil ratio which exists when the well is producing wide open in the normal way. At no time should efficiency in terms of gas-oil ratio be compared between wells of different fields where conditions are always different; but for wells producing from the same sand, in the same field, an accurate basis of efficiency comparison is the term "gas-oil ratio."

I believe that the objection to a use of gas-oil ratios in expressing efficiency because of a decline in sand pressure can be taken care of. Periodic open flow gas-oil ratio tests should be made, and instead of comparing a gas-oil ratio with one existing six months or a year previous it should be compared in terms of the new open flow gas-oil ratio for that well at that particular time. This method is discussed in detail in U. S. Bureau of Mines *Serial* No. 2833, entitled, "Some Methods of Producing Flowing Wells in the Salt Creek Field and Their Effect on Gas-oil Ratios." This comparison in terms of the new normal gas-oil ratio is necessary because of the increase of ratios with the age of the well or field.

The statement was also made yesterday that a gas-lift well is the same as a flowing well. I am not convinced of that and will have to be shown. In a gas-lift, the input pressures, volume of gas, etc., are subject to control, and the only thing that can be definitely controlled in a natural flowing well is the amount of production and the flowing pressure.

Some wells will respond readily to control in reducing gas-oil ratios, and others will not. It is always possible to secure some ratio that is lower than some other gained by a different method of producing, but if the operator cannot reduce the gas-oil ratio below the figure given when flowing in a normal way through casing or tubing, there is no justification for the expenditure of time and money in trying to secure an impossible reduction.

I believe it is possible to identify the wells that will yield to control; at least, detailed work in Salt Creek brought to light certain facts on this subject, which are given in the Bureau of Mines paper mentioned.

E. O. Bennett.—I disagree with Mr. Nowels when he says that the gas-oil ratio is a criterion of efficiency. I agree with Professor Uren that the whole thing hinges on energy control and not on the gas-oil ratio.

J. B. Umpleby,* Oklahoma City, Okla.—Two papers presented at this meeting are particularly conducive to clear thinking. Lewis and Pierce pointed out that we were not particularly interested in gas-oil ratios except as they are a measure of energy. They said that nothing had been published previously on this point. Pro-

* President, Goldelline Oil Corpn.

fessor Uren makes the same point, however, in a paper also presented at this meeting. Several engineers made the same distinction at Ponca City. It can scarcely be too strongly emphasized that the relation between the gas energy and per barrel production is such that anything that will conserve that energy in the sand and make it produce more oil at the surface is what we as engineers are after.

J. R. McWilliams,* Tulsa, Okla.—There is a subject I have not heard discussed at this meeting and I believe it is worthy of attention. It might be termed, "A More Efficient Utilization of Gas and Energy During the Natural Flowing Life of a Well." In our gas-lift work we equip our wells in such a manner as to compress a minimum amount of gas to produce a maximum amount of oil, and why should we not follow the same procedure where the gas energy contained in the reservoir serves the dual purpose of propelling the oil into the drilled hole and lifting it to the surface? It seems ridiculous to flow a small well unrestricted through 6-in. or 8-in. casing, merely because it was cased in that manner.

---

* Petroleum Engineer, Skelly Oil Co.

Chapter III. Electricity in Oil Fields

Use of Electricity in the Mid-Continent Field

By D. L. Johnson,* San Angelo, Texas

(Fort Worth Meeting, October, 1927)

Only general treatment of a subject of such scope can be given in a short paper, therefore, except in a few instances, statistics and descriptions of specific installations are omitted.

The earlier applications of electricity to the production of petroleum in the Mid-Continent field were widely separated chonologically, each holding a special interest, and each contributing greatly to the present development.

Electric Pumping

One of the first installations of electric pumping was on a lease near Jenks, Okla., in the Arkansas River bed, where a difficult problem was solved by the use of motors. The Arkansas River had frequent flood periods which interfered seriously with the use of jacks and pull rods. Small piers were built with old casing used as piling, and upon these were set small jacks driven by 3-hp. squirrel-cage motors. The starting switches were located on a bank and the power was furnished by a small generator, which was driven by an oil country gas engine. This installation was made in 1913 and is, I believe, still in satisfactory operation.

In 1914, the Cushing field came in and the Hill Oil & Gas Co. electrified its Shamrock property, using eight-pole Star Delta motors, rated at 10 to 30 hp. and belted through countershafts to the band wheel. Power was furnished by a small generating plant consisting of two 135-kw. machines, gas-engine driven. Considerable difficulty was experienced in the early operation of this station because of low voltage. It is characteristic of small alternating-current generators that voltage regulation will be poor with widely fluctuating loads. This field had three producing sands, and a number of wells were redrilled with the motors, and this, together with a great deal of swabbing, was responsible for the bad load conditions. However, when the wells had settled down to steady operation, the electric equipment functioned satisfactorily, and continued in use as installed until a few years ago when the present owners contracted for service from a central-station company and shut

* General Manager, Pecos Valley Power & Light Co.

down the generators. Almost all of the original 100 motors are in use today, part of them having been moved to other leases near Drumright, Okla. A certain number of these Star Delta motors were later installed in the Eldorado field in Kansas, where they were only moderately successful.

The Two-speed Motor

Out of the experience with these motors, and from California, which had led in the use of motors, grew a new type—the two-speed motor which was especially designed for oil-well service. This motor was provided with an outside switching device which, with 60-cycle current, gave synchronous speeds of 600 and 1200 r. p. m. On the low side it was rated at 15 hp. and at the higher speed, 30 hp. It also differed from the industrial motors in that it had a pull-out torque of over four as compared with two and one-half for the standard motor, and was able to handle with ease short-time overloads of several hundred per cent. It was more ruggedly built than industrial motors in general. With but slight modification, this type is still used almost universally for pumping service.

Although at the time this motor was developed, electricity had been little used in the oil field, during the next few succeeding years, a number of these two-speed motors were put into service, particularly in the El Dorado field, Kansas; at Bristow, Okla.; in the North Texas fields, and along the Gulf Coast.

More recently many motors have been installed at Mehan, Stroud, Davenport and other new fields of Oklahoma, and in the older fields, particularly Cushing, to replace gas engines. Electricity has made considerable progress in Greenwood County, Kansas. In Powell field, nearly one-half the wells are pumped by motor and a great proportion of the new Gulf Coast wells are electrified. In the Panhandle of Texas, several hundred wells are pumped electrically, in the presence of abundant gas and good water. In Crane, Upton and Pecos counties of West Texas, more than one-half of the known productive acreage is under contract to be pumped electrically. In the Big Lake pool, approximately two-thirds of the wells are motor driven and electric power is being used in deepening some of the wells to more than 6000 feet.

The relatively low speed on twelve-pole operation provides suitable pumping speeds without the use of a great amount of secondary resistance, while the higher speed and greater horsepower on six-pole operation are instantly available for hoisting by the simple movement of a single switch from the derrick floor.

The development of this motor to date has included improvements in the construction features and in the control equipment, the latter now being completely assembled at the factory, which greatly simplifies the installation of the motor. The operation of the motors in the field has been carefully watched by the manufacturers, who have promptly

corrected such faults of design as could be found, and have continually striven to build into them qualities and operating characteristics to meet the demand of the work to be performed.

Better Mechanical Equipment

The improvement of the mechanical equipment used in connection with motors has kept pace with the electrical development. The modern pumping well is usually provided with better derricks, more firmly set jack posts and samson posts, and more solid rig front, through which it is possible to transmit power with less loss than formerly. Countershafts have come into service which are a great improvement over those originally used, being of much more substantial construction and having large antifriction bearings. With the advent of electric power, this was an important consideration, as a surprisingly large proportion of the energy consumed is dissipated in losses between the mover and the polish rod. Economy in the use of electric power has been a spur to this improvement, and thus to electricity may be credited a great share of the benefits of the better mechanical equipment of today.

An important mechanical development of the last few years has been the use of a gear set to replace countershaft, belt, and band wheel on pumping wells. Several hundred of these gears are in service in the Mid-Continent, and there is a constantly growing proportion of wells so equipped. Most of the gear sets now installed are provided with cranks so that the motor drives directly through the gears to the pitman. This kind of drive is very efficient and has done much to cut down the aboveground losses and to make the use of electric power more economical. While it is reasonable to expect continued improvement in the electrical equipment available for pumping, the transmission of power to the well offers the greatest opportunity for increase of efficiency in electric pumping.

Economies Effected

In many instances important electrification in the Mid-Continent field has been undertaken because of a lack or shortage of gas, or for some compelling reason other than the belief of the user in the generally better results obtainable, but usually the economies effected have been sufficient to more than justify the use of electric power. These economies are to be discussed in another paper, therefore will be merely mentioned here.[1] With the use of electric power for pumping, there will be less shutdown time and a consequent increase in production. Operating statistics show

[1] See page 219.

a great reduction of time lost through rod and tubing trouble, rig trouble, and belts. Wells may be pulled in less time by motor than with engines, and there are no outages for cold weather. Less labor is used on an electrically operated lease than with engines.

Increase in Use of Electricity

The use of electricity for drilling, both by cable tool and rotary, has increased greatly during the last few years. Cable-tool drilling is performed either with a single large motor or by the twin-motor method, which uses two standard pumping motors. Since the power companies now extend their lines into each new field, and provide dependable power service, this method of drilling will doubtless continually increase since it obviates the necessity of providing water and fuel for steam drilling, often difficult to obtain, and expensive. Electric drilling equipment has been so developed that it needs no apology in any respect and is usually cheaper to use then any other power. In rotary drilling, there is available an electric drive which is provided with a differential gear set that regulates tool feed and maintains a fixed pressure upon the bottom of the hole, and which will, in the event of the bit being held from rotation, lift the tools free and relower them to resume drilling. A number of these drives have been in use in Gulf Coast fields for about three years, and one such equipment is now drilling a well in Oklahoma.

Electricity is finding many other applications in the petroleum industry, one of the most important being the driving of compressors for gas or air-lift stations. These electrically driven compressors are more easily transported, more quickly installed, and cost less than engine-driven compressors. They use a standard industrial motor and have high salvage value. They require less space for housing and less attendance in operation. In the Seminole field alone there are electric compressor stations with a total of approximately 50,000 horsepower.

In the Mid-Continent field, a considerable number of pipe-line stations are motor driven. A new line about to be built is to have ten 400-hp. electric centrifugal pump stations over its 124 miles of length.

An electrically operated lease may conveniently use this power for dehydration, welding, pick-up pumps, lights, as well as machine shop and similar small drives.

A number of factors have contributed to the growing use of electric power in the oil fields today: (1) a great deal of engineering study has been done looking toward economy and general improvement of operation on the part of the producing and pipe-line companies; (2) there are now fewer operators and larger holdings, usually, in the new fields which makes possible better engineering supervision and encourages these studies; (3) early in the history of each new field, power lines spread to every likely

area. The companies are fully alive to the desirability of this load, and are employing men who understand the oil industry and the use of electricity for oil-field operation. These men, together with the specialists employed by the manufacturers, may be depended upon to assist in the intelligent choice of equipment and its maintenance in successful operation.

[For discussion of this paper, see page 226.]

Use of Electricity for Oil-field Operations in Wyoming

By A. W. Peake* and F. O. Prior,† Casper, Wyo.

(Fort Worth Meeting, October, 1927)

Considering the great advance in the development and application of electricity, it is not strange that eventually a big field for its use has been found in oil-field operations. So far as is known, the first electric drive in oil-field operations was in the Russian field of Baku in 1900. The first application in this country was made by the South Penn Oil Co. near Folsom, West Va. in 1903.

In 1916, electric power was first used in the Burma fields of India for drilling and pumping. Between 1916 and 1922, The Empire Gas & Fuel Co. made the first large electrical installation in the Mid-Continent fields. But although the first application was made 27 years ago, it is only within the last 10 years that oil companies have begun to look upon its use with much favor. Within the last few years, there has been a steady increase in the use of electricity in the oil fields.

The first application of electricity for oil-field operations in Wyoming was in the Lander field in 1919; the second was in 1924 in Salt Creek; and the third, and last to date, was made by the Continental Oil Co. in the Big Muddy field during 1926.

Lander Field

The electrification of oil-field operations in Wyoming was initiated by J. W. Steele, superintendent of the Producers & Refiners Oil Corpn., in the Lander field in 1919. At that time, 32 wells were being pumped from five band-wheel powers, with oil engines as the prime movers. Eight barrels of fuel oil were used for power per day and at the price of 90 c. per bbl. the fuel bill was $36 per day. It was decided to try a 15 to 35-hp. oil-field motor on one of these powers. Electric power was generated with steam at the old Wind River refinery station. This test was so successful that in 1920 all five powers were equipped with 15 to 35-hp. oil-field motors, the power being obtained from the Sinks Canyon hydroelectric station. Four of these powers pumped wells at an average depth of 1450 ft., and the fifth pumped wells at an average of 2100 ft. In 1920, the average production per day from the 32 wells was 325 bbl. The power bill on the

* Director and General Superintendent, Producing Department, Midwest Refining Co.

† Superintendent Electric Plants, Midwest Refining Co.

five powers for the first four years after electrification amounted to approximately $6.35 per day. This pioneer installation was successful from the beginning and has been operating successfully ever since.

Big Muddy Field

In 1926, the Continental Oil Co., one of the larger operators in the Big Muddy field, arranged with the Mountain States Power Co. in Casper to build a 33,000-volt transmission line to serve its oil-field operations in the Big Muddy field and the refinery operations at Glenrock. As soon as power was available, a rotary equipment with Hild-drive motor was ordered and started to work. Nine wells have been drilled with that equipment, averaging 3050 to 3075 ft. deep. For this work, 240 ft. of 10-in. conductor is set, and when the well is finished a string of 6⅝, 6¼ or 5³⁄₁₆-in. casing is run and set on the top of the Wall Creek sand. This equipment has averaged a well about every 30 days, including 8 days for skidding the rotary derrick, 2 days for rigging up and 18 to 20 days for drilling. As soon as the hole is completed to the top of the sand, the rotary derrick is skidded and a pumping derrick is installed. Cable tools are run in the pumping rig, and the well is drilled, shot and cleaned out and put on production.

Humphrey No. 43 was drilled with this Hild-drive rotary equipment to a depth of 3059 ft., using 45,600 kw-hr., with a total power cost of $633.20, or a little over 20 c. per foot.

The first 925 ft., to the Shannon sand, is drilled with an Urbco bit, which has been very successful in drilling the shale in this territory. After the Shannon sand is reached, fishtail bits tipped with stellite are used. For Big Muddy rotary drilling this bit combination seems to work out very successfully.

Three wells are being pumped with 15 to 35-hp. two-speed oil-well electric motors. On one of these wells, Ideal Union tool gears are used and on the other two, Nutall gears. Power is used also for running pumps in the water station, which delivers water to the different operations in the field.

The Continental refinery at Glenrock is using power from this line for the usual types of refinery operations. In the field about 80,000 kw-hr. are being used per month, and at the refinery about 120,000 kw.-hr. are being consumed per month.

The electrification of Big Muddy is progressing and the power consumption is increasing every month as more wells are being pumped and drilled with electricity.

Oregon Basin

The latest power development for oil-field operation in Wyoming is in the Oregon Basin field near Cody. A private company has contracted to

buy power from the government hydroelectric plant at the Shoshone Dam above Cody and to deliver it in the field for drilling and pumping operations. This line will be completed in the next month or so and it is expected that many of the new wells to be drilled will use electric power.

Salt Creek Field[1]

The Salt Creek oil field is in Natrona Co., Wyoming, approximately 45 miles north of the city of Casper. It is the largest pool that has been found in the Rocky Mountain region and one of the largest in the United States. The field is situated on a great dome with a closure of about 1500 ft., which rises at the northern end of a long anticline extending north-northwest by south-southeast for fully 25 miles. The productive area includes parts of Townships 39 and 40 North and Ranges 78 and 79 West of the Sixth Principal Meridian. The Teapot oil field occupies a minor dome at about the center of the same anticline and adjoins the Salt Creek oil field on the southeast.

In the early days of the Salt Creek field, members of the engineering department of the Midwest Refining Co. considered the possibilities of electrification but the first serious move toward electrifying the field was late in 1920, when the writers made an inspection trip through the California fields, gathering data on the methods, equipment and costs of electrical operation. The findings of this trip together with an estimate of the cost of electrifying Salt Creek and data setting forth the advantages of electrical drive over steam and gas-engine drives were made up in 1921 into a bound report entitled "Electrification of the Salt Creek Field." This report was presented to the Directors of the company and later a condensed report was made to a committee, which recommended the electrification program.

Preliminary plans had already been worked out and it was decided, in order to safeguard the expenditure of so large a sum of money, to call in the firm of McClellan and Junkersfeld of New York City as consultants. Mr. Junkersfeld looked over the location, plans, choice of machinery, and estimates and gave his written approval of the whole project. The result was that the Board of Directors, in October, 1923, approved the electrification plans and authorized necessary expenditures.

The site for the plant had already been selected and a temporary camp was at once established and excavation of the plant site was started. There was no railroad to the field when the first of the equipment and material arrived and it was necessary to haul it from Casper, a distance of 50 miles. By Apr. 28, 1924, when the erection work began, the railroad was completed and in operation to Midwest. This still necessitated hauling material a distance of 6 miles to the plant site and the trucks

[1] E. L. Estabrook and C. M. Rader: History of Production of Salt Creek Oil Field, Wyoming. Petroleum Development and Technology in 1925 (1926) 199.

were often in difficulties on account of the very bad condition of the roads. Work progressed steadily, however, in spite of all obstacles, and the plant was in operation and supplying power for field uses on Dec. 15, 1924.

The entire design, choice of equipment and construction was handled by the Engineering Department of the Midwest Refining Co. under the direction of a committee composed of A. W. Peake, W. R. Finney and F. O. Prior, and the work was under the direct supervision of F. O. Prior.

Electric Plant at Salt Creek Field

The generating plant is on the east bank of Salt Creek in the Northeast quarter of Section 36-41-79, and is of 25,000 kw. capacity. The building is constructed of steel and reinforced concrete; it is 150 ft. long by 115 ft. 6 in. wide. The boiler room is on the east side of the main building and the turbine room on the west side, with a heat bay in between. The electrical bay, containing the switchboard, house distribution panels and the power transformers, is on the west side of the building and the switching station is between the bank of the reservoir and the electrical bay.

The Boilers

There are four boilers, built by the Babcock & Wilcox Co., of horizontal, cross-drum, sectional header water-tube type, set in steel casings. Each boiler has a steam-making surface of 12,960 sq. ft. and a furnace volume of 7460 cu. ft. The boilers are equipped with interdeck type of superheaters above the sixth row of boiler tubes and each has a surface of 1998 sq. ft. The boilers operate at 275 lb. pressure and 200° superheat. Residue gas from the Salt Creek gasoline plant is used as fuel, and fuel oil is installed as a standby should anything happen to the gas supply. The firing aisle is shown in Fig. 1.

The stacks are 96 in. in diameter by 60 ft. high, supported on structural steel built into the building and boiler structure. Induced-draft fans are provided which draw the burnt gases from the boiler and discharge them through the stacks.

Feed water for the boilers is furnished by two Cameron, 4-in., six-stage, 400-gal. per min. pumps operating at a speed of 1750 r. p. m. One of these is driven by a 150-hp. Terry noncondensing steam turbine, and the other by a 150-hp. Westinghouse slip-ring motor.

A steam system from the boilers to the turbines and the condensed water from the turbines to the boilers is a closed system so that only condensed water is handled in the boilers. Make-up is furnished by two high heat level evaporator systems, each consisting of two Griscom-Russell evaporators having a capacity of 6000 lb. per hour. The steam

from these units is condensed in two Griscom-Russell evaporator condensers. All boiler feed water is passed through an Elliott deaërator capable of removing air and gases from 170,000 lb. of water per hour.

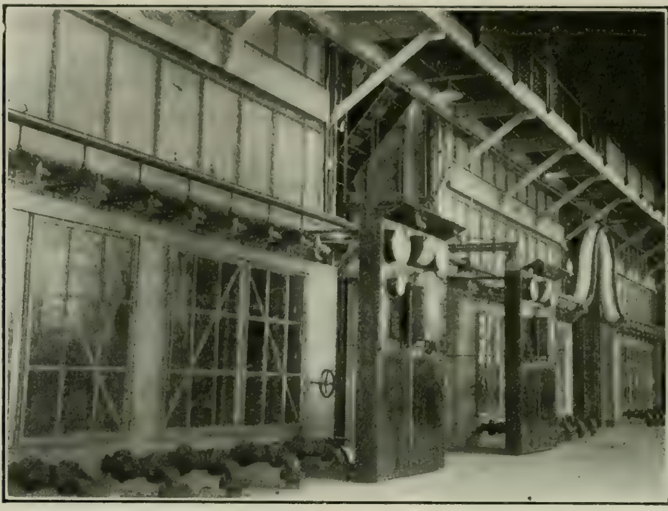


Fig. 1.—Boiler-room firing aisle. Note Pyrex doors on burner fronts.

Generating Units

The two main generating units are Allis Chalmers horizontal reaction-type steam turbines (Fig. 2) direct connected to three-phase, 60-cycle,

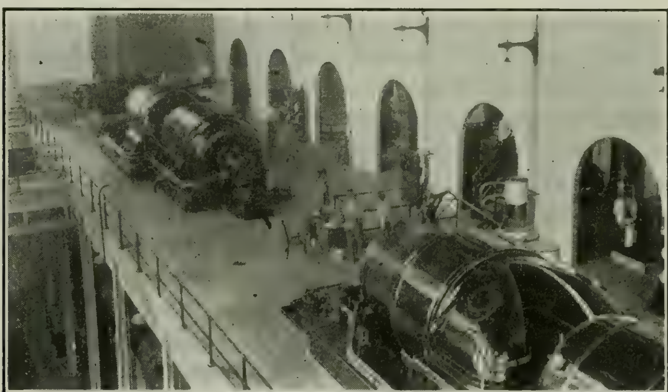


Fig. 2.—Turbine room.

6600-volt generators. These units operate at a speed of 1800 r. p. m. and have a capacity of 12,500 kw. at 80 per cent. power factor. A house turbine is provided for generating power for the plant auxiliaries during emergencies when the main units are off the line. This unit is a General

Electric, 3600-r. p. m., horizontal, noncondensing steam turbine direct connected to a three-phase, 60-cycle, 480-volt, star-connected alternating-current generator with a rating of 500 kw. at 80 per cent. power factor.

The air for cooling the two main generators and the house turbine generator is drawn from outside the building through louvers and Reed air filters, where the dust is removed. It is then led through ducts to the generators where it is used for cooling. After passing through the generators and becoming warmed, the air passes under the boilers to the burner fronts, where it is mixed with the gas for combustion in the furnace.

Condensers

Under each main generating unit is an Allis Chalmers, two-pass, surface-type condenser (Fig. 3) for condensing the exhaust steam discharged by the main turbine units. Each of these condensers has 3400 Muntz metal tubes of 1-in. diam., each 18 ft. long; or 61,000 ft. of tubes,

Fig. 3.—Condenser-room floor.

making a total of 16,000 sq. ft. of cooling surface per condenser. Circulating water for the condensers is provided by two Cameron 24-in. centrifugal pumps, each with a capacity of 20,000 gal. per min. against a head of 63 ft. These pumps are driven by 400-hp. Westinghouse slip-ring motors. The water for these pumps comes from the reservoir through traveling screens and an intake tunnel to the pump suctions.

House service water is handled by three 5-in. Cameron centrifugal pumps, which get their water from the same source. These are driven by 50-hp. Westinghouse motors at 1750 r. p. m. and have a capacity of 500 gal. per min. against a 250-ft. head.

Control Instruments

Instruments are situated about the plant for control of operations. In the boiler room there is a general boiler-room instrument set-up; as well as individual set-ups for each boiler, so that boiler feed and boiler

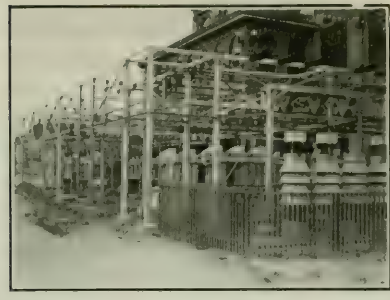


FIG. 4.—OUTSIDE SWITCHING AND BUS STRUCTURE.

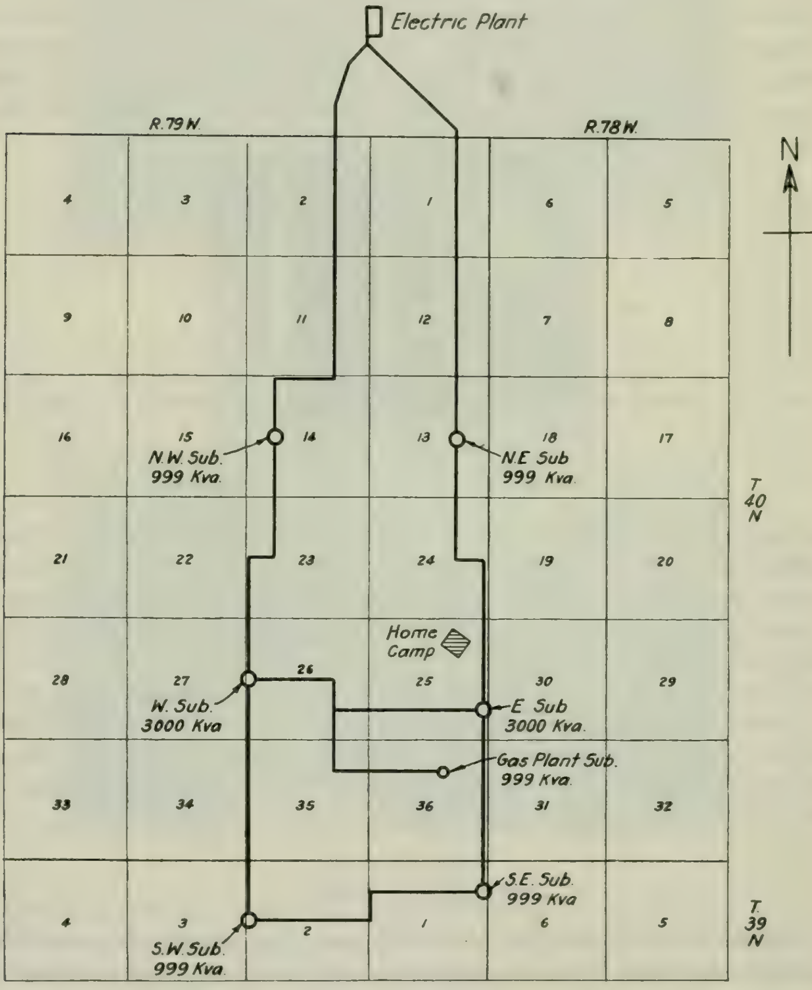


FIG. 5.—DIAGRAM OF 33,000-VOLT LINES AND SUBSTATIONS, SALT CREEK FIELD.

firing conditions can be controlled to a very fine degree. Instrument boards are also provided for each turbine.

Electric Power

The main units generate at 6600 volts and each is tied directly to a three-phase, 15,000-kva., water-cooled transformer where the voltage is stepped up to 33,000 volts. From these transformers the electricity passes through a system of circuit breakers and disconnects to either of two 33,000-volt buses. Two 33,000-volt feeder lines serve the field and either line may be connected through disconnects and oil circuit breakers to either of the 33,000-volt buses. Power is also obtained from the 33,000 volt bus through either of two 1500-kva. 33,000/440-volt, three-phase transformers, the low side connecting to a double 440-volt bus system serving all house auxiliaries.

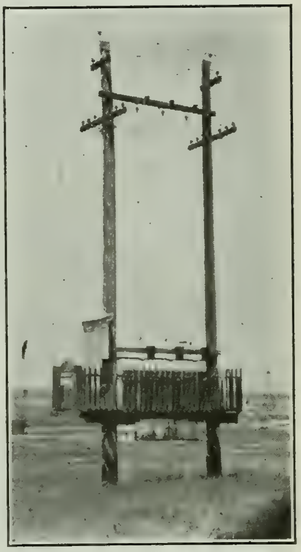


FIG. 6.—STANDARD LEASE SUBSTATION.

In the switchboard room are the bench board and all electrical instruments necessary for the control of the electrical system in and about the plant. From this bench board it is possible to operate all the outdoor circuits, to take temperature readings of the generator windings and of the transformers and to read voltage, current, power factor, and temperature on any or all the units installed. All the switchboard, transformers and bus equipment was furnished by the General Electric Co. The outside structure is shown in Fig. 4.

The 33,000-volt main feeders to the field take in the properties operated by the Midwest Refining Co. in the Salt Creek field. There are six main substations on these lines, three on each side of the field. The east and west substation and the southeast and southwest substations are tied together with 33,000-volt circuits guaranteeing the minimum shutdown time from line trouble. Fig. 5 shows the layout.

Out of each of the six substations, four 4000-volt circuits feed out over the leases so that a 4000-volt line is available at the lines between the 40-acre tracts. Lease substations (Fig. 6) step the voltage down from 4000 volts to 440 volts for use of individual well operations. These substations are located so that each takes care of two 40-acre tracts. With this system the maximum flexibility is obtained. Sectionalizing switches are installed both in the main substations and on the lines in the field, so that work can be done on the lines and new connections made with the minimum shutdown time and the minimum loss of load.

Drilling at Salt Creek

The Salt Creek Dome is outlined by an escarpment of Shannon sandstone with beds of Colorado shale, Upper Cretaceous, outcropping in the center. The first oil sands to be produced were in the Frontier Formation, Upper Cretaceous, and are locally known as the First, Second and Third Wall Creek Sands. Of the three, the Second Wall Creek sand has been by far the most productive. Other sources of production are the crevices in the shale above and below these sands. Below the Frontier sands is the Lakota, a proved productive oil sand in the Dakota group. Still deeper are the Morrison, Cretaceous (?), and Sundance, Jurassic, which are proved production. Still deeper are the Chugwater, Triassic, and Embar, Tensleep, Amsden and Madison, Carboniferous, which are prospective oil sands. Each of these formations has produced commercial oil and gas at various localities in Wyoming and Montana.

The First Wall Creek sand, in which the wells vary in depth from 975 to 1475 ft., has a productive area of 4351 acres and averages 136 ft. in thickness. The Second Wall Creek sand has a productive area of 21,450 acres and averages 70 ft. in thickness. The wells in this sand vary from 1344 to 2866 ft. in depth. The Third Wall Creek sand, from which there are very few wells producing at this time, is found from 220 to 250 ft. below the top of the Second sand and averages about 20 ft. in thickness. The Lakota sand has a productive area of 2032 acres and averages 40 ft. in thickness. The wells vary from 2370 to 2622 ft. in depth. Shale oil may be found anywhere in the field. The wells vary in depth from 500 to 2200 ft. and the productive area is 8525 acres. This shale oil must be taken when found, as a well drilled only a few feet away may miss it entirely. It is the practice in the Salt Creek field to suspend drilling whenever shale crevice oil is found in amounts of 25 bbl. or more per day. Drilling is suspended until an adequate production test has been made and is then resumed or a new hole started, as determined by the staying qualities of the shale production, which may last only a few weeks or may continue for years.

The Morrison sand, which is from 10 to 20 ft. thick, is found approximately 110 ft. below the Lakota sand and has been proved productive in two wells on top of the structure. There are three Sundance sands, totaling a thickness of 150 ft.; the top one being approximately 200 ft., the second approximately 400 ft. and the third approximately 550 ft. below the Lakota sand. These three sands have been proved productive in two wells on top of the structure and the first two have been proved productive in one well on the edge of the productive Lakota sand area.

At the present time (June 1, 1927) there are 287 First Wall Creek, 1611 Second Wall Creek, 12 Third Wall Creek, 76 Lakota, 3 Sundance, 85 Frontier shale wells and 20 Lakota shale wells, or a total of 2094 wells capable of producing oil in the Salt Creek field.

The methods used in drilling and casing Second Wall Creek wells are approximately as follows: 40 to 80 ft. of 15½ or 12½-in. conductor pipe is set and cemented in. A dry hole is drilled to the top of the First Wall Creek sand and 10-in., 45-lb. casing is then run and hung on clamps with the shoe within 50 to 100 ft. of the sand. A 10-in. hole is drilled through the First sand and far enough below to make certain that no more oil or water will be encountered. At a point from 150 to 225 ft. below the top of the sand, 8¼-in., 28-lb. casing is then cemented with sufficient cement

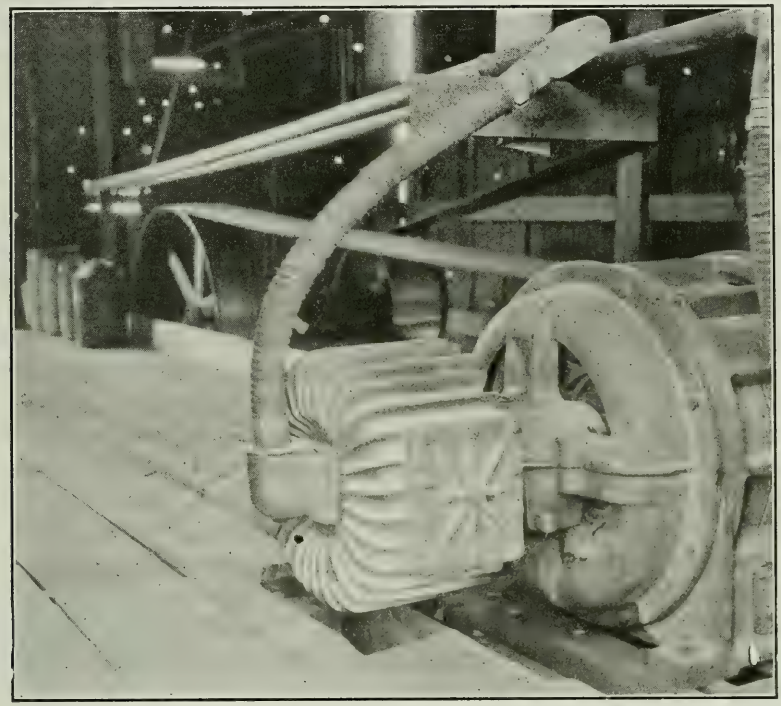


FIG. 7.—DRILLING MOTOR (75-HP.), SHOWING GASPROOF EQUIPMENT AND LEADS IN CONDUIT FROM CONTROL HOUSE TO MOTOR.

to extent 100 ft. above the sand. When the hole is within a few feet of the point at which the second sand is expected, some operators reduce the hole and "rat-hole" ahead to find the top of the sand. When it has been located, the hole is reamed out and a good casing seat obtained on the cap rock. An oil string of 6⅝-in., 20-lb. casing is landed on the shoulder at the top of the sand and the well is ready to drill in. The casing strings in the Lakota wells are about as follows: 15½-in. conductor pipe, 12½-in. casing to the top of the First Wall Creek sand, 10-in. casing to 30 ft. below the bottom of the Second Wall Creek sand, and 8¼-in. casing to 2100 ft. deep in some wells and to the top of the Lakota sand in others.

Where the 8¼-in. stops at 2100 ft., 6¼-in. is then run to the top of the Lakota sand.

All the drilling in the Salt Creek field is done with cable tools. Rotary equipments were tried at one time but were found unsatisfactory and there has been no reason to make a second trial. For drilling with standard cable tools two types of equipment are available, 75-hp. General Electric or Westinghouse electric drilling equipment or the two-motor 15/35-hp. Westinghouse equipment. Both of these types of equipment have been used successfully. Somewhat special motor equipment is used, as the slip ring of the motor must be gasproof on all our drilling equipment (Fig. 7). The method of gasproofing these motors was worked out by the writers with the General Electric and Westinghouse companies before any application of electric motors for drilling was made in the Salt Creek field.

For equipping a drilling well a permanent steel rig, a belt house and a motor house are built. The rig itself is equipped with reinforcing legs for drilling which are removed as soon as the well is put on production. The drilling motors are installed in the permanent motor house on timbers which are easily moved and set up on new locations. The controls are all installed and permanently wired up in a small motor-control house, which can be moved complete after the well is drilled. In this control house is the entrance switch to which the line wires lead. A switch and transformer is provided for the lightning circuit and switches are provided for the blower and heating circuits. A permanent watt-hour installation is wired into the cable on the control-house wall so that the actual kilowatt hours used on each well may be obtained. A curve-drawing watt meter is also permanently installed, so that the tool pusher may have a permanent record of the actual drilling and bailing time or the time of any other operation that may be taking place. The control house is always placed at some distance from the rig in order to avoid fires that might be caused by sparks from the control equipment.

The actual control at the headache post is handled in the conventional fashion. A push button is also installed at the headache post so that in emergencies the motors may be stopped by merely pushing the button. An indicating ammeter is installed at the headache post. This gives the driller an idea of just how much power is being used at all times. The drillers find this very helpful in gaging their operations; especially in fishing and running casing.

Electric heaters are provided for the dog house and are tied in to a permanent switch in the control house by rubber-covered cable which may be rolled up and moved with the heater. Blowers driven by electric motors furnish air for the forges for dressing drilling bits. These are also connected to a permanent switch in the dog house by rubber-covered cable, which may be wound up and moved with the drilling equipment.

In drilling wells in the Salt Creek field, it is necessary to mud or cement certain strings of casing. For this work, we have motor-driven Gardner mud pumps set up on trailers, so that they may be easily moved from well to well. There is a 200-amp. receptacle on the side of the motor house and a long rubber-covered cord with a plug on the end is permanently attached to the mud-pump motor. In this way connection may be made safely by the drilling, mudding and cementing crews without the aid of an electrician; in fact, the whole set-up has been designed to reduce the rigging-up time and to eliminate as much electrical labor as possible.

At the present time, in Salt Creek, we have drilled wells with electrical equipment to the First Wall Creek, Second Wall Creek, Lakota and Sundance sands. We have had very good results with electrical drilling for the past three years, and have had little difficulty in instructing the drilling department in the use of electric power. In practically every case the drillers and tool pushers have found that they could do everything with electricity that they had previously done with steam, and do it much more smoothly and, for many operations, more quickly.

During 1925 we drilled 214 wells with electricity and 149 wells with steam, at a saving of 85.46 c. per ft. of electric wells over steam wells. Table 1 gives the important data on the wells drilled during the year 1925.

TABLE 1.—*Data on Salt Creek Wells Drilled during* 1925

	All Wells		Difference	Total Wells Drilled
	Electric	Steam		
No. of wells drilled	214	149		363
Total feet drilled	370,313	271,423		641,736
Average depth per well	1,730	1,822		1,768
Days drilling	11,375	10,186		21,561
Average days per well	53.2	68.4	15.2	59.4
Average feet per day	32.6	26.6	6.0	29.8
Total drilling cost	$2,924,382.82	$2,375,558.88		$5,299,941.70
Average cost per well	$ 13,665.34	$ 15,943.35	$2,278.01	$ 14,600.40
Average cost per foot	$ 7.8976	$ 8.7522	$ .8546	$ 8.2588
Total kw-hr. used	4,100,990			
Average kw-hr. per well	19,164			
Average kw-hr. per foot	11.1			

Since January, 1926, all drilling has been done by electricity. During 1926, we drilled 301 wells, with a total footage of 538,592 ft., at a cost of $8.14 per ft. In 1927, the drilling campaign is not so heavy, an average of only about 10 wells a month being completed.

ELECTRIC PUMPING

When motor pumping of the wells in the Salt Creek field was first considered several methods were carefully investigated. It was first

decided that the most satisfactory method for the majority of the wells would be beam pumping with pumping rig irons installed, the outfit being driven by an individual motor. On account of small wells, it was also decided that the use of jacks driven from a central band-wheel power would be more economical in a limited portion of the field. Various types of individual motor-driven jacks were inspected, but after careful consideration were not adopted. This left the motor-driven beam pumper (see Fig. 11) with pumping rig irons for the greater number of the well installations and the motor-driven band-wheel power for special installations.

Motor-driven pumping equipment was being used in the California, Texas and Mid-Continent fields. Both the Westinghouse and General Electric companies had developed for this service what is known as their 15 to 35-hp. pumping motor. This is a double-wound motor capable of pumping wells on the 15-hp. side at 600 r.p.m. and of cleaning out the well or drilling deeper on the 35-hp. side at 1200 r. p. m. The electric control for this equipment is located in the motor house and is operated by the means of rope wheel from the headache post, this control being necessary when cleaning out or pulling rods and tubing. The drive consists of an endless belt from the motor to a countershaft with a standard 90-ft. belt from the countershaft to the band wheel. This installation is highly flexible and any work may be done on a well by merely changing from the 15 to the 35-hp. side of the motor.

Since this equipment had already been developed and was in use, about 80 units of this type were purchased for the Salt Creek field when the program of electrification was started.

The choice of equipment for oil-well pumping is influenced by many variables. The amount of sand in the oil, the amount of gas encountered, the gravity of the oil, the amount of water, the length of the pumping stroke, the number of strokes per minute that the well is pumping, the size of tubing, the temperature or climatic conditions, and the depth of the well, all have a direct bearing upon the type of equipment and the power required. After installing these equipments various tests were made and it was found that, because of local conditions in the Salt Creek field, the power input on the 15-hp. side of this motor was so small as to make the efficiency and power factor of this equipment very poor.

There are various types of equipment on the market for power-factor correction, such as synchronous and static condensers. The cost of these is very high and they do not correct trouble at the source, which is, of course, the best way to get at such a problem. With this in mind, it was decided to install a few 5-hp. constant-speed squirrel-cage 1200-r. p. m. motors. This equipment has inherently a better power factor and hence the power requirement of the well would more nearly load this motor, a better system power factor could be obtained. These

small motors were installed at once and complete data obtained towards making some decision on the matter.

The benefit of this type of drive was immediately evident, as the average power factor was increased from approximately 20 per cent. to 60 per cent. The total investment for small pumping motors plus the special equipment for cleaning out and for pulling jobs was 60 per cent. less than if we had used 15 to 35-hp. motors at each well. The motor was able to pump a well, the only drawback being the lack of power for cleaning out or pulling rods and tubing. This latter feature was taken care of as will be explained later, so it was decided to buy for pumping duty motors of the constant-speed type, of 5, 7½ and 10 hp., the size of the motor being determined according to the power required by the individual well. Counterbalances were installed on all beam pumping wells, thus cutting to a considerable extent the power consumption and also giving a smoother pumping motion, which is much easier on the pumping equipment.

Early during the electrification, two motor-driven band-wheel powers were installed. The first was driven with a 40-hp., 1200-r. p. m. slip-ring motor of variable speed and the second by a 40-hp., 1200-r. p. m. constant-speed squirrel-cage motor. These installations demonstrated that a high-torque motor was advisable, so a 15 to 35-hp. pumping motor with its control was tried, as this equipment has an inherently high torque. This installation was very successful, so four other powers now have this type of motor drive.

The Midwest Refining Co. has approximately 1260 beam motor-driven pumping wells and 95 pumped from motor-driven powers.

Nature of Oil at Salt Creek

Salt Creek crude is a paraffin-base oil with an average gravity of 37.3° Bé., a gasoline content of from 25 to 40 per cent. and a paraffin scale content of approximately 5 per cent. It has a viscosity (Saybolt Universal) varying from 71 sec. at 60° F. from the Third Wall Creek sand to 260 sec. at 60° F. from the First Wall Creek sand.

Various Data of Pumping at Salt Creek

The amount of power consumed by a beam pumping well is shown by our records to average around 60 kw-hr. per well per day. As the power is metered by leases, and any pulling or cleaning-out operations are shown on the same meters, this figure is probably too high by from 5 to 10 per cent. The power used for pumping varies with different wells, as mentioned. The average depth of well pumped is about 1800 ft. and the average production about 20 bbl. per day. This would give a

figure of about 3 kw-hr. per barrel of oil or about 0.017 kw-hr. per 100 ft. lift per barrel of oil per day for beam pumpers in Salt Creek.

Table 2 shows some of the principal figures from tests that were made to determine the amount of power used by a beam pumper. The wells tested were nearly all considerably larger than the average for the field and hence the power consumption per barrel of oil produced was quite a bit less than the 3 kw-hr. shown above. Table 3 is a grouping of some of the figures of Table 2. The tests are too few to draw any rigid conclusions but the results are interesting nevertheless. Group A

TABLE 2.—*Data Grouped According to Size of Motor*

Well	Depth of Well, Feet	Size Tubing, Inches	Length of Stroke, Inches	Strokes per Min.	Prod. Bbl. per Day	Per Cent. Water	Horsepower of Motor	Kw-hr. per Day	Kw-hr. per Bbl.	Kw-hr. per Bbl. per 100 Ft. Lift
31A NE 11	2716	2	29	20	70	12	5	112	1.60	0.059
27A NW 12	2410	2	29	18	21	0	5	16	0.76	0.032
6A NE 13	2174	2	21	24	37	0	5	87	2.35	0.108
4A NW 14	2327	2	29	24	95	0	5	107	1.13	0.049
19A NE 13	2090	2	29	20	15	0	5	65	4.33	0.207
1A SW 25	1600	2	36	25	253	0	5	107	0.42	0.026
15A SE 24	1868	2	36	20	126	0	5	101	0.80	0.043
29X SW 13	1301	2	22	20½	123	72.9	5	53	0.43	0.033
16A SW 25	1123	2	36	24	119	0	5	143	1.20	0.107
13A SE 25	1940	2	36	16⅔	230	0	5	77	0.33	0.017
3A SE 25	1715	2	36	24¾	40	0	5	94	2.35	0.137
6A SE 22	2220	2	29	20	121	0	5	110	0.91	0.041
9A NW 23	1694	2	29	20	55	0	5	83	1.51	0.891
6A NE 23	2450	2	36	20	17	0	5	63	3.71	0.151
16 SE 14	1386	2	36	24	14	0	5	50	3.57	0.257
7A NE 1	1798	2	29	20	22	0	5	64	2.91	0.162
36A NE 1	2017	2	29	20	54	0	5	66	1.22	0.061
6A SW 6	2038	2	29	20	23	0	5	110	4.78	0.235
19A NE 1	1818	2	29	20	43	0	5	117	2.72	0.150
Aver. of above 19 Wells...	1931	2	31	21	78		5	86	1.10	0.057
21A SE 12	2469	2	29	24	100	0	7½	100	1.00	0.041
16A SW 11	2785	2	21	24	27	16	7½	71	2.63	0.092
16A NE 15	2750	2	29	20	43	0	7½	80	1.86	0.068
4A NE 14	2123	2	29	20	85	0	7½	83	0.98	0.046
26A NW 1	1898	2.5	29	20	92	0	7½	75	0.82	0.043
36A SW 18	2665	2	29	20½	17	0	7½	44	2.59	0.097
4A NE 35	1050	3	36	20½	119	0	7½	55	0.46	0.044
18A SE 25	1656	2.5	36	17½	55	0	7½	73	1.33	0.080
31S NW 23	1315	3	36	19⅔	146	24.9	7½	146	1.00	0.076
Aver. of above 9 Wells....	2079		30	21	76		7½	81	1.06	0.051
15–1 NW 23	1190	3	36	23	405	28.3	10	96	0.24	0.020
7A NE 22	2385	2	29	20	57	0	25–10	113	1.98	0.083
17A NE 24	1846	3	44	20	480	0	35–15	208	0.43	0.023
20A SE 25	1701	3	36	18	127	0	35–15	105	0.83	0.049
6A NW 24	1660	3	29	20	171	0	35–15	166	0.97	0.058
1A SW 22	2264	2	36	20	70	0	35–15	135	1.93	0.085
12A SW 22	2490	2	36	20½	108	0	35–15	341	3.16	0.127
35A NE 1	2004	2	29	24	25	0	35–15	118	4.72	0.235
Aver. of above 6 Wells....	1994		35	20	164		35–15	179	1.10	0.055
Aver. of all wells shown...	1970				100			101	1.01	0.051

shows that the smaller producers use more power per barrel of oil regardless of depth; Group B shows that the deeper wells use more power per barrel of oil but less per barrel of oil per 100 ft. lift, and Group C shows that the wells that are being pumped with a long stroke use more power regardless of depth.

For wells pumped by a band-wheel power, the power consumption is 0.99 kw-hr. per 100 ft. lift per barrel of oil per day.

We are unable to give a direct comparison between operation costs of gas-engine drives and electric-motor drives because we do not have leases operated by the two types of drives on which conditions are similar. However, we are lifting oil from 1260 pumping wells averaging 20 bbl. of oil per day for 15 c. per bbl. These wells require considerable pulling and cleaning out to keep them in condition for efficient production. In view of adverse weather conditions in Wyoming, this lifting cost is much better than could be attained without electric power and is much better than that of neighboring leases using gas-engine equipment on beam and power wells.

Table 3.—*Data Variously Grouped*

Wells	Average Depth Feet	Stroke Inches	Strokes per Min.	Bbl. Aver. Prod.	Kw-hr. per Day	Kw-hr. per Bbl.	Kw-hr. per Bbl. per 100 Ft. Lift
A.—Grouped According to Production							
6	2140			194	156	0.804	0.038
8	2105			19	66	3.474	0.165
B.—Grouped According to Depth							
4	2377			106	165	0.644	0.022
7	1281			168	93	0.550	0.043
C.—Grouped According to Length of Stroke							
3	1763	36	23	59	100	1.700	0.096
3	2087	21	23	62	70	1.129	0.054

Pulling Rods and Tubing by Electric Power

Small pumping motors were tried for pulling rods but, although they were able to do the work, they required the use of two or three lines, which slowed down the job considerably. Therefore portable equipment was purchased, of sufficient horsepower to do the work easily and quickly and to pull the maximum number of wells in a day.

For rod-pulling jobs, 32 outfits were purchased, each consisting of a 20-hp., slip-ring, hoist-type motor driving a hoist of the single-drum

type with two compartments. The drum has a capacity of 1800 ft. of ½-in. rope, 1150 ft. of ⅝-in. rope or 800 ft. of ¾-in. rope, and the whole outfit is mounted on a 1½-ton Dodge-Graham truck. A receptacle similar to the one used in beam-pumping motor houses is mounted on the control equipment and a flexible rubber-covered cable similar to mining-machine cable is fitted with a plug on each end. One plug is inserted into the receptacle on the truck and the other into the receptacle in the motor house.

For pulling tubing we have 24 outfits consisting of 40-hp. motors connected to hoists of similar design but heavier than the rod-pulling

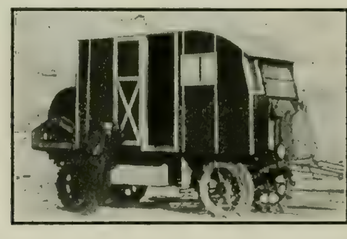


Fig. 8.—Pulling equipment, 40-hp.

hoists. Thirteen of these are mounted on F. W. D. 3-ton trucks and eleven of them on trailers, which can be pulled by a Fordson or by any other motive power available. These outfits are also capable of swabbing, cleaning paraffin or bailing. There is also one 30-hp. motor and hoist mounted on a F. W. D. 1½-ton truck, which can be used for any pulling job. The 40-hp. outfits are all housed in. (Fig. 8.)

Cleaning Out by Electricity

When the eighty 15 to 35-hp. motors, which were first purchased for beam pumpers, were released from that duty it was decided to try them at cleaning out, at which they were successful. The motor and controller are mounted as a unit on a structural steel framework which is easily moved. Two small foundation piers are placed in position when needed. It requires only from 2 to 4 hr. to move in clean-out equipment, place on piers and connect to countershaft ready for work. The same countershaft is used for both pumping and cleaning out. For the electrical connections a standard hook-up was designed which consists of leads from the pole in conduit to a standard receptacle which is fastened to the wall inside the motor house. Leads are taken off ahead of this receptacle to a small 440 to 110-volt transformer, so that lights are always available. The small pumping motor is connected to the circuit by means of a plug which is inserted into the receptacle and the starting switch is always in circuit when the plug is in place (Fig. 9).

The connection for the clean-out motor is easily made; the 5-hp. plug being removed and the 15 to 35-hp. plug inserted into the receptacle. The 6-in. endless belt from the motor to the countershaft is replaced by an 11-in. endless belt of the same length, and the well is then ready to clean out. (See Fig. 10.) An average clean-out operation takes from one to three weeks, and as the installation of the equipment is quite simple this method easily takes care of the cleaning out work to be done in the field.

With these outfits, portable sump pumps are used. These are motor-driven 3 by 4 duplex pumps, some of which are on skids and some on wheels. Portable dog houses are used on clean-out jobs. These contain electric heaters, and in addition to being used as a shelter for the clean-out

FIG. 9.—STANDARD-BEAM PUMPER, SHOWING REMOVABLE PLUG AND STARTING SWITCH.

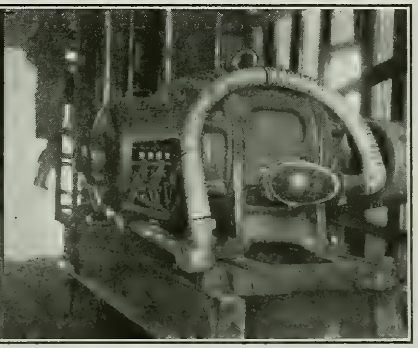


FIG. 10.—CLEANOUT MOTOR IN POSITION IN STANDARD-BEAM PUMPING HOUSE.

crew in bad weather, are used for storing tools and equipment. These houses are all mounted on skids.

When it is necessary to run a night tower on clean-out jobs, floodlights are provided to light the rig.

For cleaning out wells pumped by band-wheel powers a Star rig driven by gas engine is moved in and the same methods employed as though no electric power were available. It may be advisable to drive these with electric motors but to date it has not been done because gas engines also furnish motive power for moving the Star rigs around the field.

FIELD PUMP STATIONS

Previous to the electrification of the field the oil was pumped from the field batteries to the pipe-line tank farm by means of steam pumps, which necessitated an installation of boilers at each pump station. Now these pump stations, of which there are 135, are nearly all motorized. The majority of the pumps are 4 by 10-in. duplex power pumps driven by 25-hp. squirrel-cage, 440-volt, 1200-r. p. m. motors through silent chain drives. Each tank battery is equipped with 1000-watt floodlights (Fig.

11) placed on poles at points selected to give the best lighting to the platforms and gages. They are controlled by a switch placed on the same poles as the floodlights, man height from the ground.

Plans are being discussed for the electrification of No. 1 pump station, which pumps to the Casper refinery all the oil produced or purchased in the Salt Creek field by the Midwest Refining Co. These plans are in the formative state only, although the electrification of this station was contemplated in the major program.

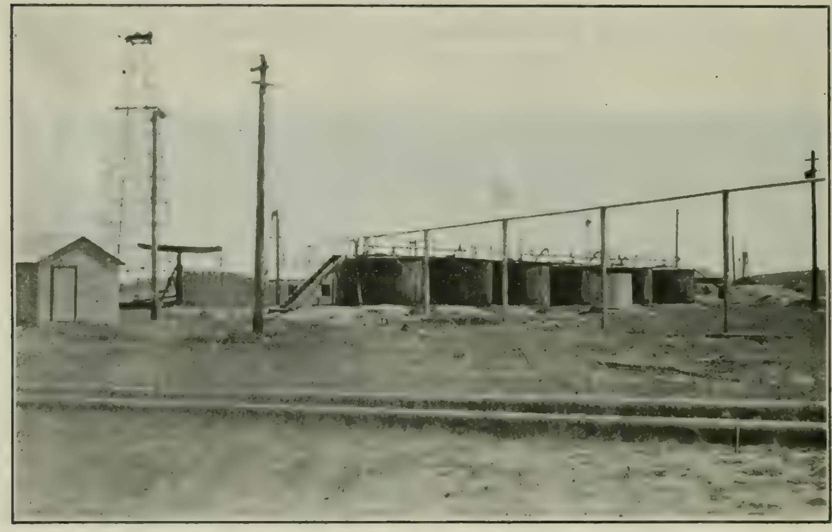


FIG. 11.—FLOODLIGHT INSTALLATION FOR TANK BATTERY. STANDARD-BEAM PUMPING INSTALLATION IS AT LEFT SIDE OF CUT.

ELECTRICAL HEATING APPLICATIONS

This company has done much experimental work on heating by electricity. The first application was a flow-line heater to keep bad lines open during cold weather and to eliminate water so as to avoid steaming oil in the stock tanks. The heater consists of a 6-ft. piece of 12½-in. casing standing vertically, with the bottom and top ends closed. The flow line enters halfway up and the fluid as it fills the casing surrounds the immersion heating elements which are inserted in the top. The oil then overflows into a vertical pipe which is connected to the outlet. A ball float and balanced valve is arranged at the bottom to draw off any water that may collect and a thermostat is inserted in the top of the device between two of the heating elements, to prevent dangerous overheating of the elements in case the flow line should cease to discharge. These heaters are of three capacities—5, 7½ or 10 kw.—and 31 heaters have been installed. Results of three tests with heaters of this type are given in Table 4.

TABLE 4.—*Results of Tests on Flow-line Heaters*

Size of Heater, Kw.	Oil Discharged from Heater Bbl. per Day	Water Drawn Off Bbl. per Day	Atmospheric Temperature	Temp. of Fluid at Inlet, Deg. F.	Temp. of Oil at Outlet, Deg. F.
5	69	5	40	56	83
10	145	71	26	82	107
10	288	31	22	76	107

The company has also developed an electric heater for the bottom of a well. Several tests have been made on increasing production by heating in the bottom of the well and the surrounding sand to eliminate paraffin, which might be holding back the flow of the oil from the sand to the well. This heater is 440 volt, single phase, 20-kw. capacity, and is run on the tubing below the pumping barrel. The heater is connected to the surface by means of a protected cable through which the current is passed from the control equipment on the surface to the heater in the well. A temperature device is run with the heater, so that accurate temperatures can be kept during the heating operation. This device consists of a coil of copper wire which has been calibrated for resistance at different temperatures. It is connected to the surface by a small two-conductor cable. Dry cells are used for the source of power and the resistance of the device is taken by means of a Wheatstone bridge and galvanometer.

The well is put on a production test and as soon as a week's settled production has been obtained the heat is turned on. By means of the temperature device, the temperature of the oil in the bottom of the hole is checked and enough heat is applied to keep this temperature as near as possible to 225° F. With the well still pumping, the heating is continued for a week. The next step is to shut the well down and continue the heating at the same temperature, giving the well what we call a "soaking test," which generally continues for 48 hr. The last step is to start the well pumping again and continue the heating for two days at the temperature of 225° F. This step is to keep any loosened paraffin in suspension so that it may be pumped from the well.

After the heat has been turned off, accurate production records are kept to determine the gain, if any, introduced by heating. In three or four wells an increase of 16 per cent. in production has been obtained, but it is not known how long the increased production from these wells will continue. One well has shown an increase of approximately 800 per cent. From the data on record, it is believed that a large portion of this increase will be permanent for a sufficient length of time to repay the expense of heating. The experiments are being continued and data are being collected as to the proper types of wells to heat and the heating of these wells to increase production.

Our next experiment was with an electric tubing heater, designed to keep paraffin from forming in the top 800 to 1200 ft. of tubing in a well. These heaters range in size from 10 to 40 kw. at 440 volts; the size depends on the size of the well that is to be treated for paraffin accumulation in the top of the tubing. The heater is designed so as to not obstruct the flow of oil in the tubing and so that the well can be pumped while the heater is in place and working. This tubing heater has been used very successfully on our properties in the Panhandle district in Texas, where the paraffin accumulation in the top 1200 ft. of tubing in the wells is a very serious production problem. At one well where a tubing heater has been working for about three months it has not been necessary to pull the tubing on account of paraffin accumulation. Several of these tubing heaters have been built and will be used in the Panhandle district on our properties in the near future.

We are working on the design of a heater for stock tanks. As described, the water is being separated from the oil by the use of electric lead-line heaters and automatic water traps. As soon as a number of these are installed we plan to do away with the steaming of stock tanks for water elimination and use an electric heater only for gravitating the oil from the stock tanks to the field pumps during cold weather.

Fluid-level Devices

In order to intelligently produce a pumping well it is necessary to know the fluid level in the well. The first fluid-level indicator we made consisted of a float and a bottom plunger housed in a piece of perforated pipe. One contact was arranged above the plunger and one above the float. These contacts were connected tó the top of the well by means of a two-conductor cable. This circuit is energized with 110 volts from the lighting circuit in the well house. On one side of the circuit there is a lamp, which is lighted when the float is raised, by striking the oil and making contact. Another lamp is placed between the circuit and ground, and is lighted when the bottom plunger touches ground, thereby completing a grounded electric circuit between the lamp, the plunger and the other side of the metal circuit.

This device is run on an armored cable from a motor-driven reel installed on a truck. The length of the cable is measured, so that the distance from the top of the well to the oil level can be found when the indicating lamp is lighted. A further check is obtained after the device is run farther into the oil and the bottom plunger strikes the bottom of the well and lights the second indicating lamp. The distance the cable is run in between the times that the lamps light gives a measure of the actual number of feet of fluid in the well and is a check on the previous reading from the top of the well to the fluid level. The reading obtained when the bottom plunger strikes the bottom of the well and its indicating

lamp lights also gives a check on the depth of the well at that time, which may be compared with previous records to determine whether the hole is clean or has filled up with any bottom sediment.

This device serves the purpose but it has two disadvantages: (1) that the rods have to be pulled in order to take the fluid level, which is not serious, as wells often have to be pulled for production purposes; and (2) that it is not recording.

We have since devised a fluid-level recorder which fastens below the working barrel and which is arranged to record the fluid level on a chart. This device is actuated by the head or pressure of the column of oil in the hole on a flexible diaphragm, which operates a Bourdon tube such as is used in a pressure gage. The shaft of the Bourdon tube is direct connected to the shaft of a Selsyn transmitter, which in turn is connected by means of a five-conductor cable to a Selsyn receiver on the surface. The Selsyn receiver is connected to a mechanism with a chart and pen, which records the fluctuations in the liquid level. The portion of the mechanism in the well is enclosed in a 4¾-in. casing, which is perforated below the flexible diaphragm to allow the pressure to act on the diaphragm. The cable connecting the two Selsyns is run outside of the tubing.

The Selsyns, or small self-synchronizing motors, are similar in outward appearance to a three-phase induction motor. In this case two of them are used, one a sender or transmitter and the other a receiver. When properly connected, both rotors maintain a fixed relation to the stator windings. If the position of one rotor is changed, the other will take a similar position. The rotors are shuttle-wound with definite poles, and the winding is connected through slip rings to a single-phase source of alternating current. The same source is used for exciting the transmitter and for the receiver. When the supply circuit is closed an alternating current is impressed upon the rotors, and as the transmitter rotor is turned by the shaft of the Bourdon tube the receiver rotor will follow at the same speed and in the same direction. The reason for this synchronous operation is that the single-phase current in the rotor induces voltages in the three legs of the stator circuits. These three voltages are unequal and vary with varying positions of the rotors. If the receiver rotor is in exact correspondence with the transmitter rotor, the voltages induced in the receiver stator equal and balance those induced in the transmitter stator, so that no current will flow in the stator or secondary circuits.

Thus when the supply circuit is closed and the transmitter rotor is turned by a movement of the Bourdon tube, the receiver rotor is turned an exactly equal amount. The recording chart is calibrated in feet-head as determined by experiments with the apparatus and records each movement of the receiver rotor, or each change in head, on the flexible diaphragm at the bottom of the well. While this apparatus has not been

used enough to record any definite results, it should, barring unforeseen difficulties, prove accurate enough for our purposes and furnish very valuable information as to the variation of this fluid level in a pumping well during the pumping operation. This is extremely important on part-time or intermittent pumping wells.

Automatic Control of Part-time Pumping

When the production of a pumping well in Salt Creek is large enough the wells are pumped 24 hr. a day. When production falls off to a certain point, part-time pumping must be initiated to reduce the wear and tear on equipment, as there is no use in pumping a well unless oil is being produced. This means that a well may be pumped 20 hr. a day and be down 4 hr.; pumped 16 hr. a day and be down 8 hr.; pumped 12 hr. a day and be down 12 hr.; or any other combination, depending on the amount of production, size of tubing, pumping speed, length of stroke, etc.

Heretofore the only practical method of part-time pumping has been, for instance, on a well that makes its production in 12 hr.; to pump the well for 12 hr. and shut it down for 12 hr. Theoretically, however, the maximum production cannot be obtained in this manner. Maximum production may be obtained by pumping 30 min. and shutting down 30 min. out of each hour. The theory is that just after a well has been shut down because of pumping off, the well will fill up with oil again at a high rate for a certain length of time. This rate will be maximum just after the well has been shut down and will decrease with time because the pressure in the sand tending to force the oil into the hole has a greater head to work against and thus is less effective. After the well fills up at the maxi mum rate for 30 min., pumping should start and continue until all of the oil in the hole has been pumped out, and pumping should then be discontinued for 30 min. By this method the oil would be produced from the well at the fastest rate it flows into the hole, and therefore the greatest production would be obtained from the well at the minimum cost.

These time intervals are used simply as an example, for each well must be studied in order to learn its most efficient pumping and shutdown periods. Because each well is a separate problem, which, in order to obtain the best results, requires its own specific intervals of pumping and shutdown time, an electrical device was developed which controls these intervals automatically. This appliance can be adjusted so that, without attention from the pumper, a well can be operated to obtain a maximum production with a minimum rod travel and therefore a minimum expense.

Actual tests have shown very encouraging results. Using this device the production is the same or greater than that secured by continuous pumping or manually operated part-time pumping; the production is steadier; the pulling cost is reduced; the wear and tear on pumping equipment is cut down materially; and the power consumption is reduced.

Gas-drive

The gas-drive, or, as it is sometimes called, "pressure restoration," is being used in the Salt Creek field. Residue gas from the casinghead gasoline plants is being used at an average pressure of 140 lb. per sq. in. in 25 key wells. The gas-drive is showing good results and plans are being made to augment this drive by the use of inert gas to be handled through a motor-driven compressor station.

Gas-lift

The Lakota wells have a total potential shut-in production of about 100,000 bbl. a day. Some time in the future our production schedule may call for the installation of gas-lift on these wells. If this becomes necessary, a high-pressure gas supply will have to be developed, as the discharge pressure on the residue-gas lines from our casinghead gasoline plants is not high enough for this work. If it becomes necessary or practical to gas-lift the production from these Lakota wells, we will install motor-driven compressor stations at strategic points. These stations will be designed to take care of the initial conditions during the gas-lift stage and will be arranged so that they may be changed for the use of gas-drive when the production declines to a point at which pressure restoration is the efficient way of handling the situation.

Miscellaneous Uses of Electric Power

Electric power is being used by the gas department for driving pumps handling water, naphtha and gasoline and also for driving air compressors in the gas-compressor plants. The gas department has 19 booster stations equipped with direct-connected gas-engine-driven compressors. The auxiliary equipment in these stations, formerly driven by a small gas engine which also drove a direct-current generator to furnish lights, is now driven by an electric motor, the current for lights being taken directly off the field transmission system through a small transformer. As time goes on, some of the gas-engine-driven compressors will be replaced by motor drives. A saving is anticipated in operation as well as maintenance of the booster stations.

Electricity is now in use in all the various camps and shops in the field. The field machine shop, pipe shop and garage, the gas plant shops, the electric plant shops, and all camps are now being served by the field transmission system. It is not necessary to give details of these applications of electricity, as they are common to all localities where electric power is available.

Conclusion

The use of electric power in the Wyoming oil fields has taken a strong hold and wherever cheap power is available it is being used for new development work where steam or gas engines have not already been installed. Electric power is being used in two of the major fields of the state, in one of the older small fields, and is now being introduced in one of the new developments which promises to be quite important. The benefits of electrification in Wyoming have met the full expectations of the operators, and it may be confidently predicted that the electrification of oil-field operations in this state will continue to have a steady growth as long as oil is being discovered and produced.

[Por discussion of this paper, see page 226]

Relative Advantages and Costs of Electric Power in Lease Operations

By L. J. Murphy,* East Pittsburgh, Pa.

(Fort Worth Meeting, October, 1927)

The production of crude oil in the United States is exceeding consumption by one-quarter million barrels per day and, with the possibilities of West Texas, this condition of overproduction, unless controlled, is likely to continue for some time. The resulting low price of oil has caused the operator to observe closely his lease operating costs. The installation of more efficient and reliable machinery has followed and it can well be said that the art of producing oil is on the threshold of a new era. In this advancement electricity has played a leading part.

This paper covers only the problem of electricity as applied to lease operation and does not consider other phases of the industry, such as drilling and pipe-line pumping, in which electric power has been utilized economically. In considering electrification of pumping wells, the first question the operator asks is whether or not his costs will be reduced and the second question is whether or not the production will be increased. The third question, although in effect it is closely allied to the first, is the cost of power. The last question can be answered only after a thorough analysis of operating conditions and a study of the power rates prevailing in the particular field under consideration. Within the past few years, the power companies have realized the desirability of a steady 24-hr. pumping load, have made their rates for oil-field service particularly attractive, and in general have shown splendid coöperation in assisting the oil companies in the satisfactory application of electric power to their leases.

When everything is taken into consideration, the first cost is practically the same for electric drive as for gas engines when pumping on the beam with individual motors. This cost, at prevailing prices, should average approximately $2200 to $2400 per installation when using 15 to 35-hp., two-speed pumping equipment, including motor and control, countershaft, motor house, belt, installation charges, and a prorated portion of the cost of transmission lines and transformers for serving a number of wells. Since there is practically no difference in the cost of the two installations, it is evident that electricity, to justify its consideration, must have a lower operating cost or produce more oil.

* Westinghouse Electric & Manufacturing Co.

Advantages of Electric Drive

Some of the advantages obtained by the use of electric drive in the pumping of wells are:

1. The shutdown time is considerably lower than with engines.
2. There are fewer rod and tubing troubles.
3. Labor costs are reduced.
4. A pumper can handle a larger number of wells.
5. The motors start easily at all times and are unaffected by weather.
6. Motors give much more continuous service.
7. Freedom from vibration means reduced maintenance on the machinery above the ground.
8. Belts have longer life.
9. The motor uses very little lubrication as compared to engines.
10. Motors pump with a steady, even flow of power.
11. The time required for pulling wells is reduced approximately one-third.

Less Shutdown Time.—In the economic operation of any important lease, it is highly imperative that the wells pump with a minimum number of hours shutdown, and any unnecessary periods of shutdown are quite likely to result in a serious financial loss to the operators. Just how much this loss in production means, it is very difficult to estimate in actual dollars, but it is evident that a loss does exist; the amount, of course, will vary with the nature of the lease, the nature of the oil-bearing strata, the amount of water to be handled, and the proximity of wells of other oil companies.

Table 1 gives a summary of the operation of four different producing companies in one field, in which the total average shutdown time for the 94 motors and the 61 gas engines is apportioned under the different causes. It will be noted that the average for all motor-driven wells is 42.5 hr. per month, or 57.9 per cent. of the 73.5 hr. per month for the gas-engine-driven wells. The figures for "D" company represent the identical wells for a four-months period with gas engines and a similar period with electric motors exactly one year later, with all conditions remaining the same at the wells, except that the total fluid raised was 2 per cent. less while the amount of water was 5 per cent. more. Since these wells were producing approximately 90 per cent. water, the amount of work done was practically the same in both cases, and all conditions are considered comparable.

On the basis of an average production of 50 bbl. of oil per day for these wells, what is the amount of the economic loss to the producer? Some operators say that to their company the loss is complete and, assuming the above shutdown figures, represents a loss of 62 bbl. of oil per well per month. Others say that the loss is only partial; still others, in large

leases, claim that the date of final extraction is only deferred, while some claim that if the well has not been shut down for too great a period, it can catch up with its production. In cases where a large amount of salt water is present, it is quite often a matter of several days before the water is pumped off and oil is again produced. In any event any shutdown time is a distinct loss to the operator.

TABLE 1.—*Comparison of Shutdown Time from All Causes with Gas Engines and Electric Motors*

Company	No. Wells	Type Drive	Time Lost in Hours per Well per Month							
			Power Off	Motor Equipment	Gas Engines	Tubing & Rods	Standard Rig	Misc. Trouble	Belt	Tota
A	46	Motors........	2.4	1.0		15.2	3.9	29.9		52.4
A	33	Gas engines....			14.3	44.3	4.5	19.5		82.6
B	20	Motors........	2.1	0.2		15.7	2.0	9.1		29.1
C	12	Motors........	2.3	0.6		15.4		22.4		40.7
C	12	Gas engines....	4.0		16.4	36.1		17.7		74.2
D	16	Motors........		0.3		22.8	3.6	4.7	0.5	31.9
D	16	Gas engines...			13.2	31.4	2.6	2.9	4.4	54.5
Average	94	Motors........	1.9	0.66		16.65	2.95	20.25	0.08	42.5
Average	61	Gas engines....	0.78		14.4	39.3	3.1	14.8	1.1	73.5

Less Rod and Tubing Trouble.—A further analysis of the table will show that one of the principal items is the time lost on account of rod and tubing trouble and that electrically operated wells are shut down less than half as much as those driven by engines. The steady flow of power from the electric motor as compared to a series of impulses from the gas engine to the rod is responsible, in a large measure, for this difference in operating results.

It is universally conceded that a uniform speed of rotation of the band wheel will cause a minimum whipping action of the rods. Such a condition of operation is impossible with any form of power now being utilized in the oil fields, but the electric motor, because of its inherent flat speed characteristics, comes the closest to accomplishing this result. Counterbalances have helped considerably in this respect, but they can never equalize the load to such an extent that absolute uniform rotation is given to the band wheel.

Lower Labor Costs.—What is the result of a 40 per cent. reduction in shutdown time on any lease? One would naturally suppose that a similar reduction in the roustabout or clean-out gang could be expected, and the experience of operators familiar with both systems of power will verify the statement that the reduction in labor costs, while possibly

not 40 per cent. in every case, is yet sufficient to be an appreciable item in the total operating expense.

Fewer Pumpers Required.—In a lease where electric motors are employed to pump the wells, fewer pumpers are required. As a result, this item also represents an appreciable saving to the operator. On account of the ease of starting in all kinds of weather, the simplicity of

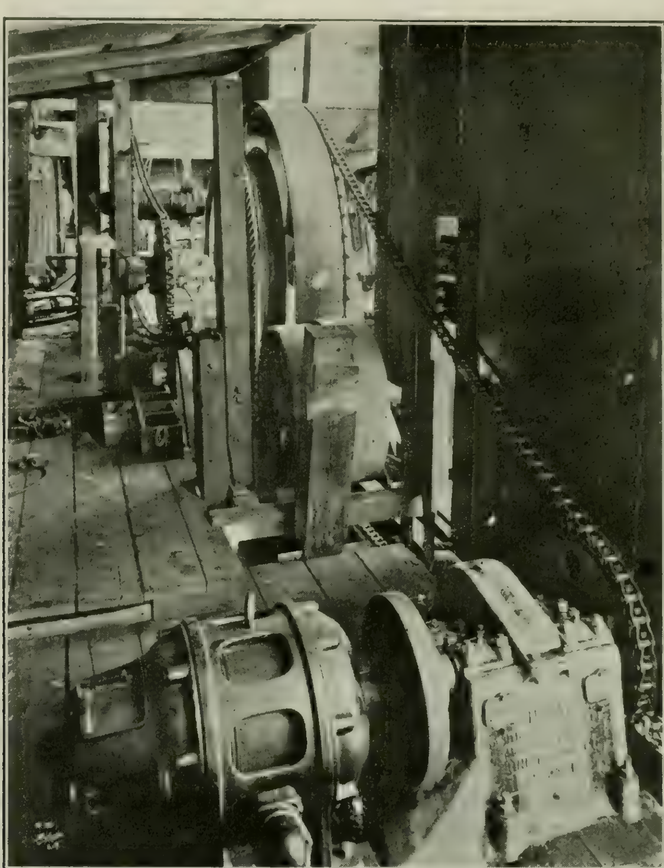


FIG. 1.—INSTALLATION OF 15 TO 35-HP. PUMPING EQUIPMENT WITH SINGLE-REDUCTION GEAR UNIT AND CHAIN DRIVE TO THE BAND WHEEL.

construction, and the fact that lubrication is required only every six months, the pumper is able to spend a minimum amount of time at each rig making adjustments, and all these features of the electric motor are combined with less wear and tear on the mechanical equipment. As a result, the number of motor-driven beam wells that the pumper can handle satisfactorily will average around 15 or 16, although there is a case on record where four pumpers per shift handled 132 wells, or an average of 33 wells per man.

In a smaller lease, having not more than eight wells, one pumper should be able to handle the entire lease regardless of the type of a driving equipment employed, and it is admitted that no saving in pumping labor can be made in such cases.

Motors Give More Continuous Service.—For continuity of service, motors are much more reliable than any other oil-field power. They are not affected by a shortage of gas, by frozen water pipes, by water in the

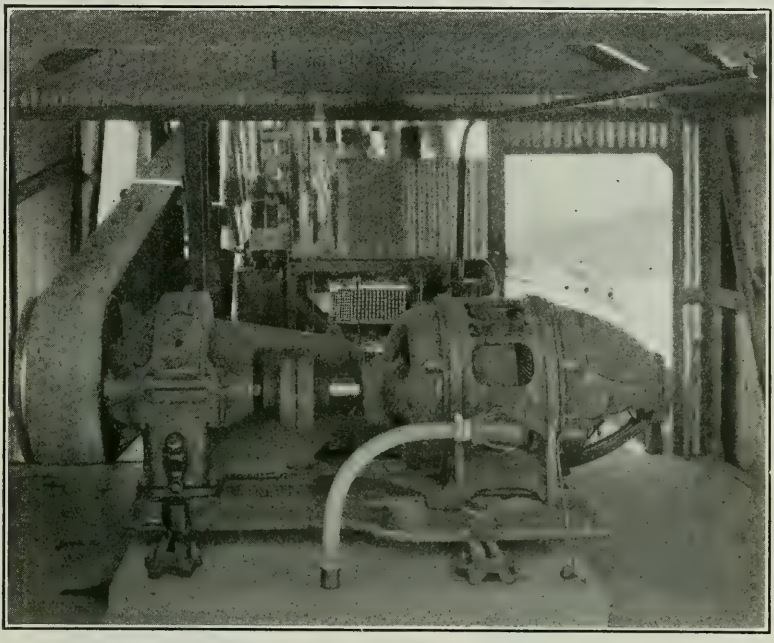


FIG. 2.—INSTALLATION OF A 20 TO 50-HP. TWO-SPEED PUMPING EQUIPMENT WITH SINGLE-REDUCTION GEAR UNIT AND BELT DRIVE TO THE BAND WHEEL.

gas line, nor do they require the back-breaking hours of labor in tramping the flywheel to start a well pumping on a cold winter night. Instead, the pumper has only to turn the controller to start the well to pumping.

A number of years ago, interruptions on the power companies' lines were rather frequent, but the modern power systems, with their extensive protective relay systems, and their facilities for furnishing power from a number of sources, can no longer be termed unreliable. The power company operators are to be congratulated on the splendid service they are furnishing the oil fields. Referring to Table 1 again, it will be noted that in every instance the combination of the hours for power off and the shutdown time for the motor equipment is less than one-fourth the time off for the gas engines.

Reduced Maintenance and Depreciation on Equipment above Ground.—Because of the steady even flow of power from the motor, belt and rig

maintenance will be decreased considerably. There are only two wearing parts in the motor, the bearings and the brushes, and, for this reason, lower maintenance and lower depreciation can be expected. The 430 motors of the South Penn Oil Co. at Folsom, W. Va., have operated continuously since 1904 and with very little maintenance expense. Other motors in California and Mid-Continent have been in operation for 15 years and are still giving a good account of themselves. The item of oil and grease on some leases will often run as high as $30 to $40 per well per month with gas-engine drive, most of which is directly chargeable to the engine. Since motors with the modern type of bearings require oiling

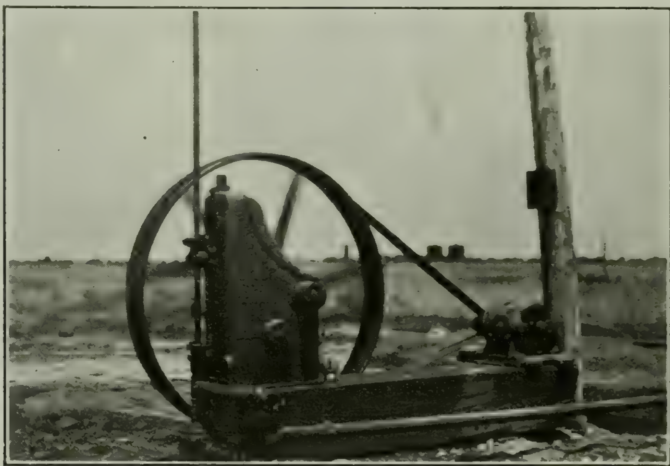


FIG. 3.—MOTOR-DRIVEN INDIVIDUAL PUMPING JACK.

not oftener than once every six months, this item of expense in an electrically operated rig is practically negligible.

Less Time for Pulling.—In pulling rods or tubing with the electric motor there are no stalling, back-firing or clutch troubles. All of the pulling crew are on the derrick floor at all times. The two-speed motor makes it possible to operate the band wheel when pulling at twice its normal pumping speed and the ability of the motor to handle tremendous overloads without slowing down appreciably insures a sustained high hoisting speed. The well is off production a shorter period of time and the returns to the operator are increased.

In dealing with this subject it has been the intention to consider the subject of pumping only in a general way, with the sole idea of pointing out some of the advantages which may be obtained from electricity. The conditions as enumerated in the table may be considered rather severe, but granting that the wells may be particularly heavy pumpers,

the fact remains that less trouble is encountered with the motor drive. One of the principal items of expense in an electrically driven well is the cost of power, and if this cost of power is justified on the heavier wells, where the power bills are comparatively high, could not electric power also justify itself on lighter wells where the total shutdown time is not as great as on the heavier wells but where the power bills are also reduced in approximately the same proportion?

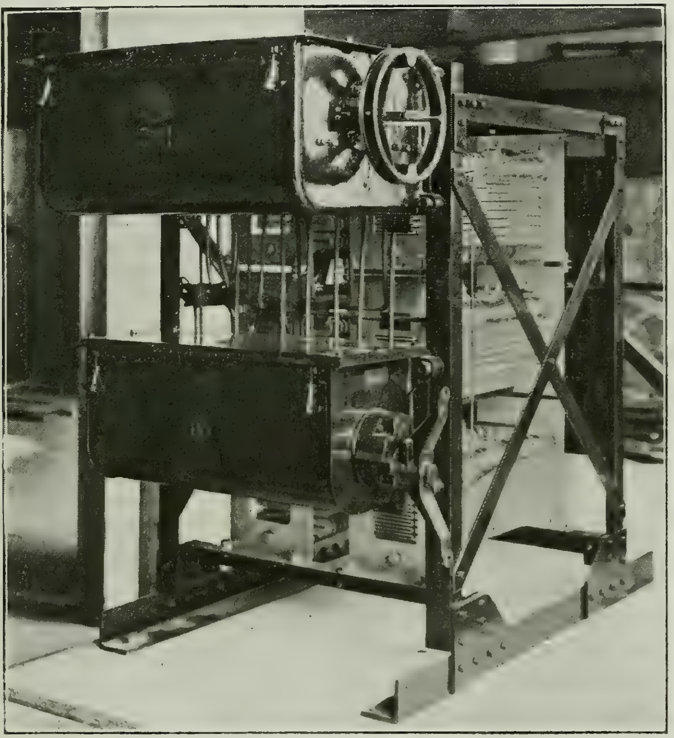


Fig. 4.—Protected type pumping control unit in which all contacts are oil-immersed.

Operating data from all sections of the country have proved that electric power is the coming power for pumping wells regardless of size or depth. The 430 motors in West Virginia have demonstrated their economy and reliability over a period of 23 years; California wells have been electrified for a number of years and the records show a lower operating cost; foreign fields are practically 100 per cent. electrified; the Gulf Coast, Oklahoma, Kansas, and Wyoming fields have accepted electricity; and West Texas is electrifying in all places where electricity is available.

Once the electric motor has demonstrated its economy in lifting oil out of the ground, it is only a matter of a short time before it is used for other applications in the oil field. Electricity is being used economically for field and rig lighting, for motors operating gathering pumps, for central powers and individual pumping jacks, for loading stations, machine shops, water pumps, camp lighting, arc welding, dehydration and gasoline-plant drives, to say nothing of its more or less recent application to compressors used in air-lift and gas-lift work. In the Seminole field alone there are over 50,000 hp. in installed motor capacity operating air and gas-lifts. The day of electricity in the oil fields is here!

DISCUSSION

[Refers also to papers of D. L. Johnson, A. W. Peake and F. O. Prior, beginning on pages 189 and 194]

E. O. Bennett,* Fort Worth, Texas.—Electricity versus gas engines and steam has been discussed in every field. We have many conditions in West Texas where we have to forget the economy of first cost. We have gases and water so bad that we cannot operate boilers; we have had heads of pistons 2 in. thick go out in three weeks, eaten through by the bad gases. The electrification of such fields has been a great relief to the operators and has proved economical in final analysis.

---

* Chief Production Engineer, Marland Oil Co. of Texas.

Chapter IV. Handling Congealing Oils and Paraffin

Summary of Existing Information on Handling Congealing Oils and Paraffin*

By C. E. Reistle, Jr.,† Laramie, Wyoming

(Fort Worth Meeting, October, 1927)

All crude oils become more viscous when chilled, but the only oils that congeal and precipitate paraffin to such an extent as actually to cause production troubles are those that contain an appreciable amount of wax.

In handling these oils of high wax content, three distinct problems may be encountered before the oil reaches the refinery. The first problem is the precipitation and accumulation of paraffin in the well, either in the oil string or on the face and in the pores of the sand. The second problem is the accumulation of paraffin and the congealing of oil in the transportation lines. The third problem is the precipitation of paraffin and the formation of tank bottoms.

Factors That Control the Solubility of Paraffin in Crude Oil

Two main factors, possibly three, govern the solubility of wax in crude oil. The first of these is temperature. The solubility of wax in crude oil increases with an increase in temperature, and as the temperature approaches the melting point, the wax becomes soluble in all proportions in the crude oil. The higher the melting point of a wax, the less soluble it is in crude oil below its melting point. All crude oils containing wax can be chilled to a point where the oil is saturated with wax. If the temperature is decreased below this point, some of the wax will crystallize from solution. Fig. 1 shows the effect of temperature on the solubility of crude paraffin in oil.

The second factor is the amount of volatile constituents and gas removed from the crude oil. Evaporation of the volatile constituents and gas lessens the volume of the oil and concentrates the solution of wax in the oil; therefore less wax can be held in solution at a definite temperature. As the natural amount of wax present in the oil is constant, this results in the oil becoming saturated with wax at a higher temperature than if the volatile constituents and gas were still in the oil. As an example of this, a fresh sample of crude oil having a gravity of 39.8°

* Presented by permission of the Director of the Bureau of Mines.

† U. S. Bureau of Mines.

A. P. I. was saturated with wax at 72° F. The temperature was held constant and the oil evaporated until it had a gravity of 37° A. P. I. Approximately 1 per cent. by weight of wax was precipitated from solution.

The possible third factor is the presence of water. Water is slightly soluble in crude oil; and it is probable that oil containing water is a poorer solvent for wax than dry crude oil, just as alcohol or acetone that contains water is a poorer solvent for wax than dry alcohol or acetone. The exact effect of water on the solubility of wax in crude oil has never been determined. The writer is working on this particular phase of the problem at the present time.

Character of Congealed Oils

When crude oils that contain wax are chilled or evaporated sufficiently, some of the wax will be precipitated or crystallized from the solution. The size of the crystals depends only to a slight extent on the rate of cooling. This is negligible, therefore, as even with slow cooling or evaporation the crystals remain small. If the crude oil is not agitated while this crystallization takes place, the crystals interlock and form a network which prevents movement and supports or holds the liquid constituents of the oil. If the oil is agitated during the crystallization, the oil remains liquid, although its viscosity is greatly increased by the presence of solid or semi-solid wax crystals. This is similar to results obtained by adding fine colloidal clay to water; if sufficient clay is added the resulting mass will become viscous. If the temperature is lowered sufficiently, the oil will congeal, even though agitation is continued. This is due to the large number of wax crystals present and also to the fact that the liquid constituents become so viscous that internal friction prevents any free movement of the oil around the wax.

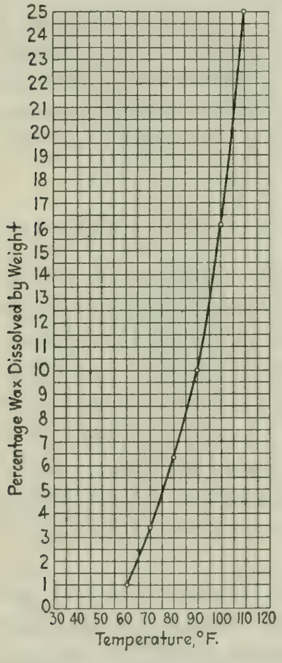


Fig. 1.—Solubility of crude paraffin wax in crude oil of 36.2° A. P. I. from the Panhandle Field, Texas.

These small wax crystals have a tendency to accumulate into small granular particles, each particle being composed of a number of the wax crystals. This is found especially in storage tanks where the oil stands over a long period of time. The formation of granular particles will usually take place more rapidly when the oil is cooled only slightly below the point of saturation, as the wax crystals then have more freedom to move and settle

out of the oil. When the oil is cooled until it has congealed, the wax crystals cannot move to form these granular particles. If congealed oil is agitated, the crystals come into contact with one another and often form these larger particles.

Waxes will remain in solution in crude oil and will form supersaturated solutions, even though the oil has been chilled to a point below where it is saturated with wax, but the wax will slowly crystallize from solution until equilibrium is established and the oil is saturated with wax at that respective temperature.

If crude oil that contains a large amount of wax is heated to a temperature above the highest melting point of the wax, another set of conditions is created. The wax then becomes a liquid dissolved in a liquid, each liquid being soluble in the other; instead of a solid dissolved in a liquid, the liquid being insoluble to any great extent in the solid. This latter case is where the wax has been dissolved in the oil at a temperature below its melting point.

If, after heating the oil to a temperature above the melting point of the wax, the oil is again cooled below the temperature at which it is saturated with wax, no crystals form. This is probably due to the fact that the wax has formed a solution of the oil in wax, and this solution of oil in wax is soluble in the oil below the temperature at which the wax would ordinarily separate out of solution if it were present as a solution of *wax in oil* instead of *oil in wax*. If the temperature is maintained below the melting point of the wax and also below that point where it is completely soluble as wax in oil, the solution of oil in wax will slowly change over to wax dissolved in oil; and as this continues there becomes an excess of wax dissolved in the oil, and some wax crystallizes out. This is the writer's explanation for the results obtained by heating high cold-test oils such as the Panhandle crude, and thereby reducing the cold test from a number of hours to several days. After standing for several days these crude oils regain their original cold test; this occurs when the oil dissolved in wax has been reconverted to wax dissolved in oil.

Character of Paraffin Deposited in the Well or on the Face and in the Pores of the Sand

The paraffin that is deposited in producing wells varies in consistency from a soft, granular semi-fluid, containing considerable oil, to a hard semi-solid wax, containing only a small quantity of oil. Usually some sand, water and inorganic silt is also present. The character of the paraffin depends primarily on the amount of oil present with the wax. This in turn is usually governed by the length of time the wax has been allowed to accumulate in the well. On standing in the well, the oil

slowly drains and works out of the wax deposit, leaving it in a more compact and drier state.

The character of the paraffin is affected also by the amount of cooling and evaporation to which the oil is subjected in the well. If there is only sufficient cooling and evaporation to cause the precipitation of a small amount of wax, the melting point will be high, as waxes with the highest melting points will be the first to crystallize from the solution. If a greater cooling and evaporation takes place, a greater quantity of wax will separate from solution, but the melting point will be slightly lower because waxes of low melting point crystallize from solution, in addition to those of higher melting points. The melting points of paraffins removed from wells in different fields are given in Table 1.

TABLE 1.—*Melting Points of Crude Paraffins*

Field	Sand	Melting Point, Degrees Fahrenheit
Salt Creek, Wyo.	2nd Wall Creek	165.4
Lance Creek, Wyo.	Dakota	181.0
Panhandle, Texas.	Granite Wash	141.2
Marietta, Ohio.	Macksburg Stray	135.2
Clay District, W. Va.	Big Indian	161.9
Bradford, Pa.	3d Sand	132.1

These crude waxes consist of a number of fractions having different melting points. Usually the wax with the lowest melting point melts at about 135° F., and fractions regularly increase in melting point to as high as 191° F. In the Panhandle, wax fractions with the lowest melting point found melted at 141° F., while those with the highest found melted at 172° F. In Lance Creek, waxes melting at from 135° F. to 191° F. were found.

Deposition of Paraffin in Flowing Wells

The accumulation of paraffin in the oil string of flowing wells forms constrictions in the pipe and retards the flow of oil. If the paraffin is not removed it will gradually fill the pipe and kill the well. As the quantity of paraffin increases, the production of the well gradually declines; it is essential, therefore, to remove or prevent it in order to obtain the maximum amount of oil available.

The paraffin deposits in flowing wells usually extend from the top of the well to a depth of several hundred feet. As a general rule, this lower limit of paraffin accumulation corresponds roughly with the depth at which the earth temperature is the same as the temperature at which the oil is saturated with paraffin, or to the fluid level in wells where the

oil rises above this point. Where a large amount of gas is produced, and where excessive cooling takes place, the paraffin often extends somewhat deeper than this.

In new fields, the oil leaves the sand at a temperature above that at which it is saturated with paraffin. However, as the oil is expelled from the well, it is cooled by the gas that is doing work in lifting the oil, by radiation of heat to the surrounding formations, and also because some of the lighter constituents are evaporated by the gas, which also produces cooling. In many cases, this results in the crystallization of wax from solution in the oil. However, the presence of free paraffin in suspension in the oil is not sufficient to cause any great amount of paraffin to accumulate in the well. It is essential, in addition to this, to have a set of conditions whereby these suspended particles of wax have an opportunity to settle out of the oil and become attached to the walls of the oil string; otherwise, they will be carried out of the well by the oil.

The most favorable condition for the accumulation of paraffin takes place between flows. During this period the oil drains back into the well, leaving a thin film of oil and suspended wax on the sides of the pipe; the oil drains away from these particles of wax, and they become firmly attached to the pipe. Additional paraffin may be precipitated from the oil film if the walls of the pipe are below the saturation temperature of the oil, especially if there is much gas being produced between flows, as this will have a tendency to remove an additional amount of the lighter constituents and raise the temperature at which the oil is saturated with wax. When the temperature of the surrounding strata is above that at which the oil is saturated with wax, the film of oil has a tendency to redissolve any suspended paraffin, and therefore very little accumulates. Sometimes when large quantities of gas are being produced during the period between flows, the film of oil may be evaporated to such an extent that it becomes saturated with wax at a much higher temperature than the bulk of the oil; in such cases the paraffin deposit will often extend below the point where the temperature of the surrounding strata is the same as that at which the main body of oil is saturated.

The amount of paraffin that accumulates in the well is governed to a large extent by the length of time elapsing between flows and the efficiency with which the oil is lifted. In wells having oil strings of the same size, there is usually a more pronounced cooling in the smaller wells, on account of the inefficient lifting of the oil and a better radiation of heat to the surrounding strata. During the periods when oil and gas are accumulating, there is a constant lifting and dropping of the oil in the well. This work on the oil by the gas lowers its temperature and also removes some of the lighter constituents. As a result of these conditions, the oil in smaller wells usually contains a larger amount of suspended paraffin. Table 2 gives an example of this cooling.

TABLE 2.—*Temperature Data on Flowing Wells at Salt Creek*

Well	Size of Oil String	Approximate Temperature of Sand, Degrees F.	Temperature of Oil at Casinghead, Degrees F.	Daily Production, Barrels	Cu. Ft. of Gas per Bbl. of Oil
8A NW¼ 13–40–79	2-in. Tubing and Packer	108	56	40	7789
16A SW¼ 13–40–79	2-in. Tubing and Packer	108	66	243	2848
31A SW¼ 30–40–79	2-in. Tubing and Packer	108	81	575	1089

In addition to greater cooling, and therefore more suspended paraffin present in the oil, there is also a better opportunity for the suspended paraffin to become attached to the walls of the pipe in these wells. The longer periods between flows allow the oil to drain more completely from the pipe in the upper part of the well; and the suspended paraffin becomes more firmly attached to the pipe, so that less of it is removed by the oil when it flows from the well. In the wells under observation at Salt Creek, there was very little paraffin trouble in the large flowing wells, but as the production declined the paraffin troubles became more pronounced. If the oil string was then made smaller so that the period between flows was shortened, the paraffin trouble decreased; but as production continued to decline, the rate of paraffin accumulation again increased. When the wells were put on the pump the accumulation of paraffin was practically eliminated, providing the proper precautions were observed. This will be discussed later.

In wells where excessive cooling takes place, or where, from other causes, a large amount of suspended wax is present in the oil, a certain amount of paraffin will accumulate and become attached to the walls of the pipe even though the periods between flows are short. It is possible, also, that some of paraffin particles become attached to the pipe as they come into contact with it while flowing with the oil from the well.

In wells that are flowed artificially by compressed gas or air, the same conditions are responsible for the deposition of paraffin, and the same methods of preventing and removing the accumulated paraffin are applicable.

In wells that are produced by means of the gas-lift or air-lift, trouble is often encountered with paraffin deposited at the foot piece or lower end of the eduction tube; and in wells where gas is jetted into the eduction tube at various points, paraffin accumulates at these places. Paraffin also accumulates along the walls of the pipe in the same manner, and as a result of the same conditions, as in natural flowing wells.

The accumulation of paraffin around the foot piece or end of the eduction tube is usually due to using excessive quantities of gas and

allowing the well to pump off. When the well pumps off, the gas flows through the eduction tube and results in a local cooling. There is often sufficient cooling and evaporation at this point to cause the deposition of paraffin, even when the well is correctly operated. It also dries the film of oil on the pipe and allows the suspended paraffin to become firmly attached. The accumulation of paraffin around the jets in the eduction tube is the result of cooling caused by the gas at this point, and of the fact that the constant wetting and drying of the surface immediately surrounding these jets allows particles of paraffin to become firmly attached to the pipe.

Methods of Preventing and Removing Paraffin from Flowing Wells

In most instances, from an economic standpoint, it is advisable to prevent the accumulation of paraffin. Sometimes, however, this is either impossible or so costly that it is preferable to remove the paraffin after it has accumulated.

In order to prevent or decrease the deposition of paraffin in flowing wells, it is necessary to produce the oil so that the conditions which favor paraffin deposition, and which have just been discussed, are eliminated or modified. Generally, these conditions can be modified by reducing the size of the oil string. This shortens the periods between flows, causes the oil to be lifted more efficiently, and therefore results in less cooling. It also often results in reducing the gas to oil ratio, and thereby reduces evaporation of the lighter constituents. When tubing is used, there is also less heat lost to the surrounding strata by radiation, as the space between the tubing and casing acts as an insulating medium. The use of back-pressure, although not always applicable or advisable, will sometimes prevent the conditions that favor the deposition of paraffin.

Circumstances often make it impossible to prevent the accumulation of paraffin by proper production methods alone. One of the most satisfactory methods to use with such conditions is to heat the oil as it flows from the well. A number of different methods of heating have been tried, and many have been found satisfactory. It is questionable, however, whether the cost of operating these methods will compare favorably with methods for removing the paraffin after it has accumulated.

Electric Heaters for Flowing Wells

One of the most common methods of heating the oil as it flows from the well is by the use of electric heaters. These heaters are of the resistance type and are usually designed to run into the well on a wire line or so that they may be attached to the bottom of the oil string. A number of types have been patented. Two types of heaters are shown in Fig. 2.

These electric heaters must generate sufficient heat so that the oil will reach the top of the well at a temperature above that at which it is saturated with wax. As a general rule, it is necessary to operate them continuously in order to prevent the deposition of paraffin. If the heaters have capacity enough to heat the oil sufficiently to dissolve additional paraffin, they can be operated intermittently. When used in this manner, a certain amount of paraffin is allowed to accumulate in the well, then the heaters are turned on, and the heated oil dissolves this accumulated paraffin.

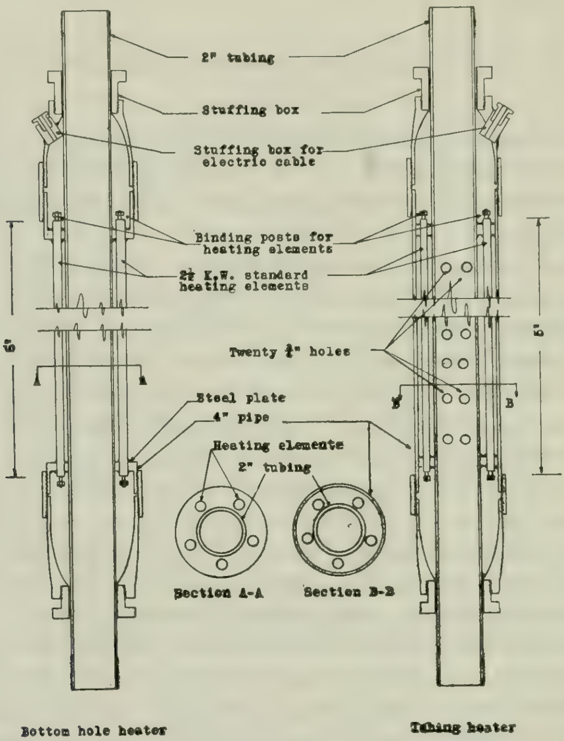


FIG. 2.—ELECTRIC HEATERS FOR USE IN OIL WELLS.

The greatest objection to electric heaters is the cost of operation and maintenance. It is very difficult to build a heater that will operate satisfactorily over a long period of time under the severe conditions existing in a well. It is difficult, also, to obtain cables for transmitting the power to the heaters. As an example of the cost of operating electric heaters, the following results are given: An electric heater was placed on the tubing of a 100-bbl. well just below the point where the paraffin started to accumulate. The oil normally reaches the top of the well at a temperature of 71° F., and with the usesof the heater the temperature was raised

to 83° F. This was found sufficient to prevent the deposition of paraffin. The heater had a capacity of 10 kw.-hr.; and estimating the cost of the power at 1¼ c. per kw.-hr., the cost of operating the heater was 12½ c. per hour—$3 per day, or $90 per month. This represents only the cost of operating the heater, and does not take into consideration other costs, such as maintenance, etc. The same well could be kept in excellent condition by the use of a paraffin knife or hook once a week. The total cost of operating these tools with a portable winch would not exceed $10 per time, or $40 per month.

Heating by Steam, Water, Oil or Gas

In some fields, steam is used to heat the oil while it is flowing from the well. The steam is usually put into the well through a coil, either inside

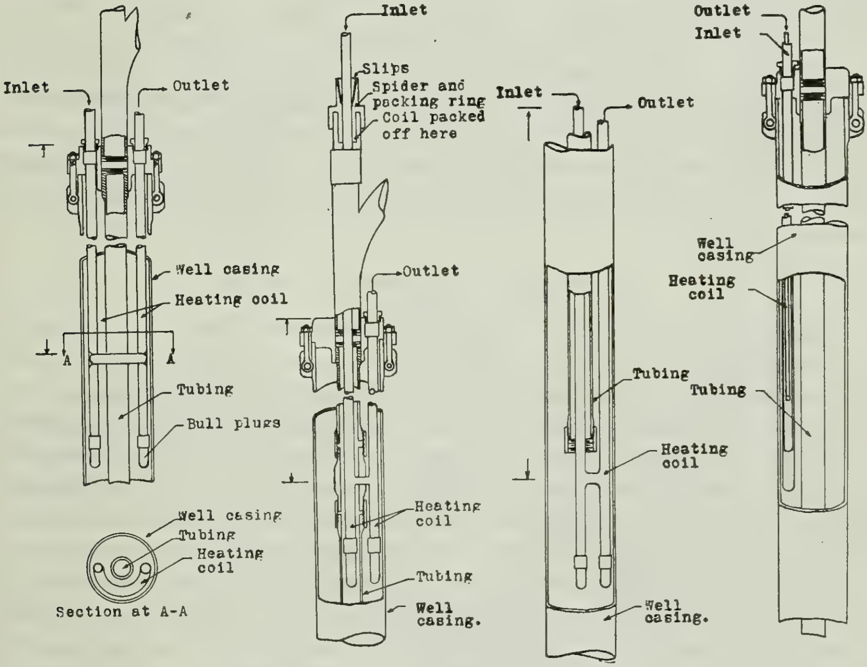


FIG. 3.—COILS FOR STEAM-HEATING IN OIL WELLS.

of the oil string or between the oil string and the casing. Generally, the coil is connected so that it returns the condensed water to the surface instead of allowing it to run into the well and be produced with the oil. The depth to which closed coils can be operated in the well is limited by the amount of pressure available to lift the condensed water. In very deep wells, especially where the oil does not have a tendency to emulsify badly, the coils are left open, and the condensed water is allowed to drop to the bottom of the well and be produced with the oil. Several types of coils

are shown in Fig. 3. These coils were described to the writer by K. C. Sclater, who used them in the South Mountain field in California.

In using steam, it is possible to raise the temperature of oil sufficiently so that it will dissolve additional paraffin. It is, therefore, customary to operate the steam coils at intervals instead of continuously.

It is questionable whether this method would be satisfactory from the cost viewpoint, unless excess steam is available without appreciable extra expense; for instance, where steam is used for pumping and where fuel gas has a very low market value. Unless this is true, it will usually prove cheaper to use the paraffin knife or hook and a portable winch.

At some wells, hot water or oil is circulated instead of steam. The same types of coils are used, and the liquid is circulated from the heater into the well and back to the heater by means of a pump. It is difficult to raise the temperature of the oil in the well very much by this method, and the cost of operation will usually be large.

In wells that are pumped by means of the air-lift or gas-lift, the ingoing gas is often heated, either by a steam heater or a gas-fired heater. It is doubtful whether sufficient heat to prevent entirely the deposition of paraffin can be transferred to the well in this manner. In most instances, where this method has been tried, it has been abandoned as unsatisfactory.

Special Tools for Removing Paraffin

Usually, it is cheaper, with flowing wells, to allow the paraffin to accumulate to a certain extent and then remove it by using special tools. These tools are of two general types: those that cut the paraffin from the tubing and allow the flowing oil to carry it from the well, and those that cut the paraffin from the pipe and also remove it from the well. Several types of these special tools are shown in Fig. 4. The paraffin knife and flow devil can be used without interfering with the production. These tools cut the paraffin free from the pipe, and it is flushed from the well by the oil. The special head shown in Fig. 4 allows these tools to be run in and out of the well without a loss of oil. In wells where the amount of paraffin is large, it is usually advisable to use the paraffin hook. This tool cannot be used while the well is flowing, and it is necessary, therefore, to use it between flows or to shut the well in. The advantage of this tool is that it removes the paraffin from the well and prevents the possibility of bridging of the loosened paraffin, as often occurs when the paraffin knife or flow devil is used on large deposits. These tools can be operated either by the standard equipment at the well, or by portable electric and gasoline powered winches.

If these tools are used at regular intervals, the amount of paraffin that accumulates will not affect production. A more detailed discussion of these tools is given in the United States Bureau of Mines *Report of*

Investigations, Serial No. 2802. The cost of removing paraffin in this manner should not exceed $10 per time, when using portable winches,

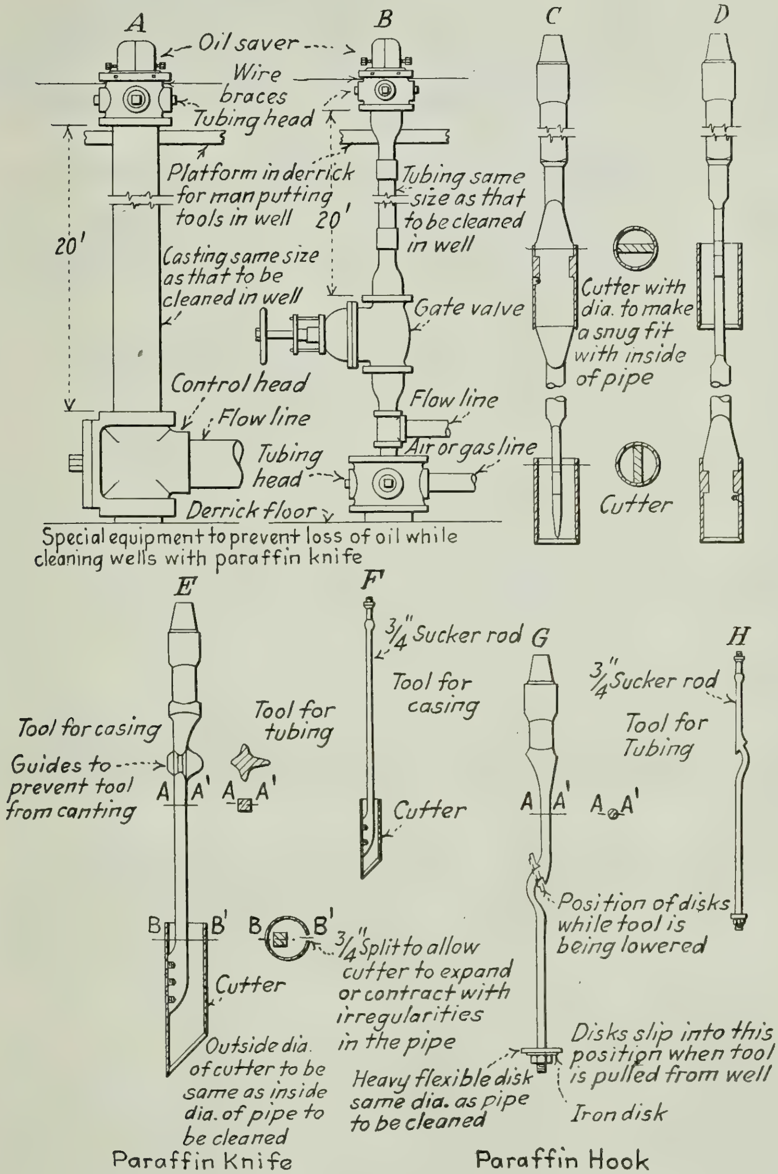


FIG. 4.—TOOLS FOR REMOVING PARAFFIN FROM OIL WELLS.

and should be much less when the well is rigged up so that the tools can be operated by the engine at the well.

Deposition of Paraffin in Pumping Wells

The accumulation of paraffin in pumping wells gradually closes up the tubing and increases the load on the rods; and if it is not removed, the load often becomes so great that the rods break under the increased strain. The presence of paraffin also makes it difficult to pull broken rods and it often becomes necessary to remove it from the tubing before the rods can be run back into the well.

The most pronounced trouble from paraffin occurs in pumping wells in which the oil flows by heads from the tubing instead of pumping steadily. When wells produce in this manner they are usually referred to as being agitated by the pump. This condition often occurs when there is a packer between the tubing and the casing, or where the casinghead is closed and any gas produced with the oil must come up the tubing. Crude oil has a tendency to remain supersaturated with gas, and when agitated this gas comes out of solution. Agitation often occurs in pumping wells where the oil enters the bottom of tubing supersaturated with gas; as the oil approaches the top, the pressure gradually decreases, and the motion of the pump is sufficient to cause the liberation of this gas from solution. The liberated gas flows the oil above it out of the well. When agitation occurs and the oil is removed from the tubing in this manner, a thin film of oil and suspended paraffin remains on the walls of the pipe, and the paraffin becomes firmly attached in a manner similar to the way in which it accumulates in flowing wells during the periods between flows.

The movement of oil is slow in pumping wells, and the radiation of heat to the surrounding strata results in the oil being cooled appreciably. Table 3 gives the tubing-head temperature of some pumping wells at Salt Creek.

Table 3.—*Temperature Data on Pumping Wells at Salt Creek*

Well	Size of Oil String Tubing, Inches	Approximate Temperature of Sand, Degrees F.	Temperature of Oil at Casinghead, Degrees F.	Daily Production, Barrels
19A NE¼ 13–40–79	2	108	63	11
36A SE¼ 25–40–79	2	108	71	30
1A NE¼ 36–40–79	2	108	73	50
29A NE¼ 24–40–79	2	108	73	65
3A SE¼ 24–40–79	2	108	73	95
23A NE¼ 24–40–79	2	108	60	30

The well 23A was producing oil by heads instead of pumping steadily, and the low temperature was probably partly due to cooling from the gas as it expanded and flowed the oil.

Paraffin also accumulates rapidly when the valves leak in wells that are pumped intermittently. This condition allows the oil to drain out of the tubing during the periods when the well is not pumped, and the paraffin then becomes attached to the pipe.

Sufficient Oil Prevents Paraffin Deposition

There is little or no tendency for paraffin to accumulate and stick to the walls of the pipe so long as it is completely full of oil. Instead, the

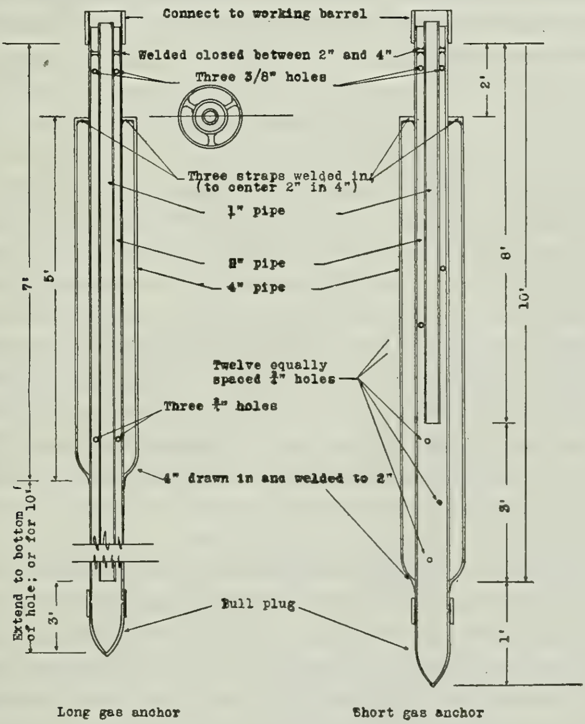


FIG. 5.—GAS ANCHORS.

paraffin remains suspended in the oil and is carried out of the well with it. Even on long standing, the paraffin will not become firmly attached to the walls of a pipe that is full of oil. If the oil is drained or flowed from the pipe, the suspended paraffin that remains with the film of oil will become firmly attached as the oil drains away from it and will remain on the pipe when again covered with oil. When the oil contains a large amount of suspended paraffin, some of it will accumulate on the rods and tubing, even under the best of conditions. The rate of accumulation

in this manner, however, is very slow; it seldom becomes hard or extensive enough to cause trouble, and will generally be taken care of by the regular pulling of the rods for other troubles.

As previously mentioned, the most severe trouble from paraffin is found in wells that flow or agitate instead of pumping steadily. This can be stopped by taking the gas that is produced with oil out at the casinghead and by using a good gas anchor remove all the excess gas that is held in the oil as a supersaturated solution. In most cases, this will result in the well pumping steadily and will completely stop paraffin troubles. Two types of gas anchor are shown in Fig. 5. When the well still has a slight tendency to flow after these precautions have been observed, a back-pressure of 25 to 30 lb. per sq. in. held on the tubing will be effective. This back-pressure has no effect on the sand, as it is held against the pumping equipment only.

Removing Paraffin from Pumping Wells

A paraffin hook can be run into the tubing on the rods after they have been pulled and the working valve removed. It is only necessary to run the tool to the depth at which the paraffin showed on the rods. When the tool is pulled from the well, it will bring all the accumulated paraffin with it. This operation can be done with the usual portable winch used for pulling rods, or with the drilling engine if the well is rigged up.

Hot solvents, such as kerosene, crude oil or gasoline, can be run into the well through the casing and pumped out through the tubing. It is difficult, however, to heat the solvent sufficiently to dissolve the paraffin deposited in the tubing in this manner. The cost of this method is prohibitive in most cases, as the rods can be pulled and a paraffin hook used with less special equipment and expense.

When large quantities of casinghead or drip gasoline are available, they can often be used for dissolving the paraffin by putting several barrels into the well and then circulating the oil for several hours by connecting the tubing into the casing. The crude oil and gasoline will successfully remove the paraffin, providing they are circulated in this manner for several hours, in order to allow them time to dissolve it. This method is applicable only where the gasoline is available at a very low cost.

Certain chemicals for removing paraffin are on the market. Most of these react with water to generate heat—700 to 800 B. t. u. per pound. The chemical is usually run into the well between the tubing and casing and allowed to react at the bottom of the well. This heats the oil, which in turn dissolves the paraffin from the tubing as the oil is pumped through it. Unless a large quantity of chemical is used, the oil will not be heated sufficiently to dissolve the paraffin. It is cheaper to remove the paraffin

from the tubing of pumping wells by pulling the rods and using a paraffin hook.

Deposition of Paraffin on the Face and in Pores of the Sand

The accumulation of paraffin on the face or in the pores of the sand decreases the amount of oil that can enter the well. This particular phase of the paraffin problem is one of the most serious, because it usually occurs in old wells of small production, in which it is often doubtful whether the increased production obtained by removing the paraffin will justify the expense incurred.

The temperature of most producing oil sands is above that at which the original oil is saturated with paraffin. Any deposition of paraffin on the face or in the pores of the sand is therefore the result of evaporation and cooling of the oil as it flows through the sand or into the well. As a field is produced the remaining oil in the sand steadily becomes heavier, due to the loss of the lighter constituents. As an example of this, the initial boiling point of oil from the second sand at Salt Creek increased from 98° to 103° F. in 1922, to 116° F. for 1924, and 142° to 144° F. in 1926. It is also of interest to note that no vacuum has been used in this field during that time. It is possible, in fields where vacuum has been used for a long period of time, that a sufficient quantity of the lighter constituents have been removed so that the oil adjacent to the well is unable to hold all of the paraffin in solution, and it has crystallized out and caused the oil to congeal in the pores of the sand. It is also possible that in many fields the gas flowing through the upper part of the sand, after the oil has been partially depleted, has evaporated the remaining oil in this part of the sand until it has reached the point where paraffin has been precipitated and caused the oil to congeal and plug the pores of the sand.

In fields where the oil is unsaturated with paraffin at the temperature of the sand, there will not be any accumulation of paraffin, provided the fluid level is maintained at the top of the sand, as the temperature of the oil in the well will be very nearly the same as the temperature of the sand. Any gas being produced with the oil cannot cool it very much, because it does not do any appreciable amount of work on the oil at this point. In most cases, the gas does not expand suddenly upon entering the well, but gradually expands as it flows through the pores of the sand in approaching the well; therefore very little cooling can result from this source. In addition to these conditions, it is improbable that any wax would be deposited on the sand, providing the fluid level was constantly maintained at or above the top of sand, even providing the oil were cooled and evaporated so that it contained suspended paraffin. Laboratory tests have shown that paraffin will remain in suspension if there is sufficient oil.

The accumulation of paraffin on the face of the sand probably takes place in wells in which the fluid level is maintained at the bottom of the sand. In flowing over the face of the sand in a thin film the oil may be evaporated to such an extent by the gas being produced that it cannot hold all the paraffin in solution, and some will crystallize out. In wells where vacuum is used, a greater evaporation of the oil takes place. In the laboratory, it has been observed that when oil, containing small suspended particles of wax, or other substances, flows over a surface in a film thinner than the diameter of the particles, these particles stick to the surface.

The raising and lowering of the fluid level by intermittent pumping should not result in the deposition of paraffin on the sand unless the oil is saturated and contains suspended particles of paraffin. If the oil is not saturated with wax, it will have a tendency to dissolve any paraffin that has been deposited on the surface of the sand while it was covered with only a thin film of oil.

Preventing Accumulation of Paraffin on the Face

If possible, the fluid level should be maintained at the top of the sand at all times. This will prevent the accumulation of paraffin on the face of the sand, even though the oil contains suspended particles of paraffin, as this suspended paraffin will not have an opportunity to become firmly attached to the sand. If the oil that accumulates with intermittent pumping is saturated and contains suspended particles of wax, the alternate covering and exposing of the sand will have a tendency to increase the deposition of paraffin.

In some fields, the producers are putting back into the sand the vapors that are made when the gasoline is weathered. These vapors, when dissolved in the oil remaining in the sand, increase its ability to hold paraffin in solution and therefore tend to prevent its deposition in the pores or on the face of the sand.

If tools are used to remove paraffin from the casing or tubing, care should be taken not to force a large quantity of it down into the bottom of the well where it may plug the sand. When heat is used to melt the paraffin in casing or tubing, the paraffin may run down and plug the sand; however, if the sand is covered with oil, this will usually be prevented, as the wax will be dissolved or remain suspended in the oil.

Electric Heaters for Use at the Face

In most cases, heat or solvents are used, either combined or separately, to remove paraffin that has been deposited on the face or in the pores of the sand.

Electric heaters can be used if they can be lowered into the well, either on a wire line or on the end of the tubing; the latter will allow the well to be pumped while the heater is in operation. The sand should be covered with oil while the heater is in use, so that it will dissolve the paraffin and carry it in suspension to the top of the well, instead of allowing it to melt and accumulate in the bottom of the well, where it might congeal when the heater is turned off. Kerosene or crude oil can be added if the fluid level will not come up to the top of the sand, or if it cannot be maintained while the well is pumping. A temperature slightly above the melting point of the paraffin should be used, as this will insure immediate solution of the paraffin in the oil that is being produced by the sand or being added to the well.

By means of a 20-kw.-hr. heater, the oil in the bottom of a well having a normal temperature of 103° F. was raised to 220° F. This temperature was maintained for several days and then the heater was turned off. The sand was heated sufficiently so that the temperature of the oil did not cool to 103° again until the seventh day after the heater was turned off.

Figuring power at 1¼ c. per kw.-hr., this heater would cost $6 per day to operate. This method of heating the sand is probably the cheapest and most economical method of removing paraffin that is deposited on the face or in the pores of the sand adjacent to the well.

Steam or Flame for Heating the Face

Steam also is used for this purpose. It is not as satisfactory as electricity because it does not obtain the required temperature so easily. The steam also cuts the oil badly and often causes caving of shale breaks within or above the sand, which necessitates cleaning with tools after the steaming operation is completed. As a general rule, when steam is used, it is carried to the bottom of the well in tubing and is there released. Superheated steam was used in a well similar to the one in which the electric heater was used. The steam had a temperature of 740° F. as it entered the well, and the temperature at the bottom of the well was approximately 230° F. The well had two strings of tubing and was pumped continuously while it was steamed. A temperature of 230° F. would melt any paraffin that might be present in the sand or in the pores adjacent to the sand, but the cost of operating steam equipment for that temperature is much greater than that of operating electric heaters, and much better results can be obtained with the latter.

Another method of heating the sand is by the use of a flame. A string of tubing with a burner attachment is lowered into the well and a proper mixture of air and gas to sustain combustion is pumped down the tubing. The gas is ignited at the bottom, either by an electric spark or by a flare lowered into the well. A small burner at the top of the tubing indicates whether the requisite proportions of air and gas are being used.

Undoubtedly, a high temperature can be obtained by this method, but it is questionable whether it accomplishes the desired results. In very small wells, the oil that accumulates during the burning operation will be burned; but in larger wells, there is a probability of a thick, tarry residuum remaining in the well after the burning operation is completed. It is also possible that the lighter constituents of the oil in the pores of the sand will be distilled off, leaving a heavy residue that will remain in the pores and plug them. It is also possible that this high temperature will tend to change the character of the sand and reduce the size of the pore openings. After using the flame, it might be advisable to add several barrels of kerosene, gasoline or crude oil to dissolve any thick residue that might remain in the well or that might flow from the sand while it is still hot. The actual cost of operating this method is somewhat less than that of the steam method but greater than the electric. The method is patented, and in addition to the cost of operation a royalty agreement must be made before it can be legally used.

Circulation of Hot Oils or Chemicals

The circulation of hot oil is often used to heat the sand and dissolve the paraffin. Generally, the well is connected to a tank containing steam coils; the oil is pumped into the tank and heated, then is allowed to run back into the well between the casing and tubing. Gasoline, kerosene, or other oils are often added to the crude oil that is circulated, in order to increase the solubility of the paraffin. Providing the oil is hot enough and the operation is continued for a sufficient length of time, paraffin will be removed, but the method is not recommended.

Chemicals that generate heat may often be used to advantage in removing paraffin from the face of the sand. It is advisable to have the sand covered with oil. The chemical heats the oil; the heated oil dissolves the wax, and can then be pumped from the well. If the chemical is used without an appreciable amount of oil in the well, the paraffin may be melted and cooled again before it can be removed by pumping, or it may congeal in the tubing while being pumped from the well. When the chemicals are properly used, satisfactory results can often be obtained at a moderate cost.

Compressed Air or Explosives Not Recommended

The use of compressed air alone for removing paraffin may result in forcing the paraffin into the pores of the sand instead of removing it. If hot gasoline, kerosene or crude oil is first added to the well and allowed to dissolve the paraffin, the air can be used to remove the solvent and any loose sand, silt, etc., that might be in the well. Compressed air can also be used in connection with revolving reamers that cut away the sand.

The tool removes the paraffin and cuts away the sand that might be plugged by the paraffin and the air carries the loosened material from the well.

The value of explosives for removing paraffin is questionable. The pressure created by the explosion might force the paraffin more firmly into the pores of the sand, or it might shatter the sand so that a layer of the surface would be removed, taking the paraffin with it.

Paraffin Troubles in Flow Lines

Two distinct problems are encountered in flow lines. The first is the deposition of paraffin as a hard layer inside the pipe, gradually increasing and closing it. The second is the congealing of the entire body of oil in the flow line. These conditions usually are met in the colder periods of the year.

The accumulation of a hard deposit of paraffin generally occurs in flow lines of wells that are producing by heads, and where excessive quantities of gas are being produced. It also occurs in the flow lines of pumping wells, where the casinghead gas is connected into the flow lines. This type of paraffin is the result of the same conditions that cause the trouble in the well, and it is necessary to prevent these conditions in order to overcome the trouble. This can be accomplished by using a gas and oil separator at the well and keeping the flow line full of oil at all times. In pumping wells the casinghead gas should be run through separate lines, to prevent the formation of hard paraffin deposits in the flow lines.

If it is impractical to separate the oil and gas at the well and prevent the accumulation of paraffin, it is necessary to remove it from the lines before the accumulation reaches the point where it seriously retards the flow of oil. This can be accomplished by running a flexible scraper through the lines occasionally. A ball of newspaper or heavy wrapping paper inserted in the flow line at the well makes an excellent scraper; the oil will force it through the line and it will remove the paraffin. When the accumulation is too hard and extensive for this scraper, it can best be removed by running steam through the lines.

The congealing of the entire body of oil in the flow lines is caused by the cooling of the oil below its pour point. If the oil is kept moving, it will not congeal at as high a temperature as when standing still, but even when kept moving it will become viscous or congeal if cooled sufficiently.

This trouble can often be overcome by using large flow lines and having the tankage near enough to the well so that the oil will reach the tank before it is cooled sufficiently to congeal. When this is not practical, it is necessary either to prevent the cooling of the line or to heat the oil.

There are two general methods of preventing the line from becoming cooled below the pour point of the oil. The first is to bury the line deep enough so that it will not be appreciably affected by atmospheric tem-

perature changes; this is usually impractical under oil-field conditions. The second method is to box a steam line with the flow line. The oil line can then be heated whenever necessary. This method is expensive, but it is one of the surest methods of preventing this trouble, and is widely used.

When there is an oil and gas separator at the well, steam coils can be used in the separator to heat the oil, but this method is likely to cause excessive evaporation of the oil and a loss in gravity. The oil can also be heated by running through a steam heater or heat exchanger, usually consisting of a small pipe inside a larger one, the oil running through the smaller pipe and the steam in the outside or larger pipe. In some fields, gas heaters, and in a few instances, electric heaters, are used. When the flow line is long, several heaters may be necessary to keep the oil heated above the congealing point. These heaters are satisfactory, providing the oil is kept moving; but when the well does not produce continuously they often fail. When the flow of the oil stops, the portion between the heaters will cool off and congeal, if the atmospheric temperature is low enough. It is advisable, therefore, where the oil is not moving continuously, to provide a method of heating the flow line throughout its entire length or to bury it.

Paraffin Troubles in Pipe Lines

Paraffin is seldom deposited as a hard layer in pipe lines, but the oil will congeal. This trouble can be partly or entirely prevented by burying the line, but in handling oils that congeal at a comparatively high temperature, it is necessary to heat the oil at various points along the line. If the oils are heated to a temperature above the melting point of the waxes that they contain, the point at which they congeal will be considerably lowered, and they will not return to their original pour point for a number of hours; in some instances, not for days. The fact that the pour point can be lowered in this manner makes it possible to handle some oils that could not otherwise be run through the lines during the winter months except by using a great number of heaters or by burying the lines 8 or 10 feet, the expense of which would be prohibitive.

Occasionally paraffin does settle out of the oil and accumulate in the bottom of the lines as a soft, granular mass; but it does not become firmly attached to the pipe, and the quantity is seldom sufficient to cause trouble. Silt, sand, etc., also accumulate, and it is advisable to run scrapers through the lines at regular intervals to prevent the building up of large quantities of refuse.

Paraffin Troubles in Storage

When oils containing a large amount of wax are placed in storage, the wax slowly settles out of the oil and accumulates as a thick, granular mass

in the bottom of the tank. This also occurs sometimes while oil is being shipped in tank cars. Usually it is mistaken for emulsion, especially where some emulsion is also present. This accumulation of wax is caused by the fact that the average daily temperature of the oil is below the point at which it is saturated with wax, and the excess crystallizes out of solution and settles to the bottom of the tank.

After oil has stood in storage for a long period of time and the excess wax has been allowed to settle out, the pour point is considerably lower than it was with the fresh oil. If this paraffin is not put back into solution, it represents a loss as tank bottoms, because few, if any, pipe lines will accept it, even if it does not contain any water, as it would settle out in the lines and cause considerable trouble. It is advisable, therefore, to put it back into solution in the oil, either before or while running the oil from storage. This can be done by removing the tank bottoms from the tank and heating them to a temperature sufficient to cause all the wax to melt and go into solution in the oil associated with it, and then mixing this heated wax with the oil from which it separated. If there is also considerable emulsion, the water must be removed before the oil is returned to the larger body of oil. This can usually be accomplished by heating the bottoms, consisting of oil, wax and emulsion, and adding a chemical. Upon running this heated oil into the bottom of a tank partly filled with hot, fresh water, the emulsion will break down, and clean oil can be taken from the top of the tank. Care should be taken not to add too great an amount of the treated oil to the original or to fresh oil, as this may cause the wax to settle out again very rapidly. It is advisable to use vapor-tight heaters and tanks while treating these tank bottoms, to prevent evaporation losses.

Summary

In this paper, the writer has tried to discuss the most important problems encountered in producing oils of high paraffin content, and also the most satisfactory methods of preventing and handling these conditions. It is impossible in so short a paper to discuss in detail all the various problems and different methods that have been tried or used to overcome paraffin deposits.

DISCUSSION

R. Van A. Mills,* Bartlesville, Okla.—First, I would like to make an addition to this very good paper—not a criticism, but an addition. I submit herewith a bibliography on this subject to make the paper a more complete summary and to take the place of the footnote references which Mr. Reistle has omitted. This bibliography was prepared by Miss Florence W. Lundell, technical librarian of the Tulsa Public Library. Miss Lundell has prepared a series of bibliographies upon different petroleum engineering subjects, for free distribution at the Tulsa Public Library.

* Mining Engineer and Petroleum Engineer, U. S. Bureau of Mines.

References on Removal of Paraffin from Oil Wells

H. Crane: How California's Mine at Newport Beach is Solving the Problem of Recovering Heavy Oil. *Pet. World* (Jan. 1926) 59, 68.

F. Gardner: How to Aid Oil from Stratum to Well. *Pet. Mag.* (June 1921) 36–38.

A. W. Golden: The Go-devil. *Oil Age* (Sept. 1922) 30–32.

A. F. Hinton: Use of New Chemical May Solve Problem of Handling Panhandle Crude. *Natl. Pet. News* (July 28, 1926) 45–46.

R. Van A. Mills: Paraffin Problem in Oil Wells. U. S. Bur. Mines *Report of Investigations Serial No.* 2550 (Dec. 1923); *Natl. Pet. News* (Dec. 26, 1923) 58–62; (Jan. 2, 1924) 67–69–70–78; *Oil and Gas Jnl.* (Jan. 3, 1924) 28, 114, 118–119, 123; *Oil Weekly* (Jan. 5, 1924) 25–26, 28–30.

H. Pennington: Overcoming Paraffin Trouble in Wells. *Oil Weekly* (Aug. 11, 1923) 24–25; (Aug. 18, 1923) 23–24, 33–34.

C. E. Reistle: Methods and Tools for Removing Paraffin from Wells. U. S. Bur. Mines *Report of Investigations Serial No.* 2802; *Oil and Gas Jnl.* (May 12, 1927) 123, 180–181; *Oil Weekly* (May 6, 1927) 51–52.

L. E. Smith: Painting Casing and Melting Paraffin. *Natl. Pet. News* (Nov. 19, 1924) 88.

Peculiar Manner of Wax Accumulation of Salt Creek Wells. *Natl. Pet. News* (Apr. 1, 1925) 48, 51.

Successful Method of Melting Paraffin in Wells Found by Hope Co. *Natl. Pet. News* (Jan. 28, 1925) 55–56, 59–60.

I. A. Unden and H. P. Bybee: The Thrall Oil Field. Univ. of Texas *Bull.* No. 86 (1916) 7–78.

P. Wagner: Paraffin Accumulation is Special Problem in Texas Panhandle Wells. *Natl. Pet. News* (Mar. 17, 1926) 28–29.

Remove Paraffin from Oil Wells. *Inland Oil Index* (Feb. 7, 1925) 3.

Hope Tries Flame in Well to Remove Paraffin. *Natl. Pet. News* (Aug. 22, 1923) 91, 94.

Patent Well-cleaning Device. *Natl. Pet. News* (July 5, 1922) 31.

Paraffin Cutter Made for Use in Wells in Texas Panhandle. *Oil and Gas Jnl.* (Dec. 2, 1926) 262.

The matter of the composition of paraffin in oil wells is interesting. I think we are dealing with a variety of waxy hydrocarbons instead of true paraffin; also with inorganic substances which tend to thicken the mixtures of oil and the waxy hydrocarbons.

In one case of so-called paraffin trouble in southeastern Ohio, the paraffin-like substance removed from the well contained enough carbonate silt to make it effervesce in hydrochloric acid. After the effervescence ceased the so-called paraffin had the appearance of good oil. There was very little, if any, paraffin present. The thickening substance appeared to be silty calcium carbonate precipitated from the water in the well.

In the Salt Creek field, a second sand well was being flowed through 2-in. tubing to reduce the gas-oil ratio. It flowed satisfactorily for about two days. Then the tubing became partly plugged with paraffin about halfway down the hole and the well would not flow. We closed the well in for 24 hr. (using gate valves in the tubing at the top of the well); then we opened it up for the same length of time. When closed in, the pressure at the top of the tubing would build up to approximately 400 lb.; when open, the pressure in the tubing at the top of the well would drop to 20 or 30 lb. By this method we could make the well flow its paraffin out through the flow line. From these facts, it appears as though the increased solubility of the paraffin in natural gas, or in a mixture of oil and natural gas, under high pressure

may be of considerable importance. Possibly the rise in temperature, when the rapid gas expansion and consequent chilling effects were stopped by closing the well in was an important factor in this softening and removal of paraffin.

I do not know to what extent paraffin is soluble in natural gas or in gas-saturated oil under high pressures, but in this particular case it was evident that the high pressure of the gas had some softening effect on the paraffin that plugged the tubing.

Mr. Reistle mentions the use of chemicals to remove paraffin from wells. Dry mixtures of strong alkalies with metallic aluminum, especially sodium hydroxide and aluminum, have been used for this purpose with some success. When these mixtures are immersed in water they react violently, generating enough heat to melt the paraffin. Sodium peroxide has also been used to remove paraffin from the face of the sands. This reagent has the double advantage of producing intense heat and liberating oxygen to burn the paraffin when it comes in contact with water. A large number of these heat-generating reagents are now on the market under various trade names but none has come into extensive use for cleaning oil wells.

On one of the old Smith and Dunn properties near Marietta, Ohio, one of the old wells was badly paraffined. The casinghead was off and the tubing was out. One of the field men inadvertently dropped a piece of lighted waste down the well. The next day the men found that well smoking copiously. In considerable excitement the pumper ran for the water bucket and quenched the fire by pouring a few buckets of water down the casing. The funny part of this story is that the production of the well was more than doubled when it was put back on the pump in the following day or two. The combustible mixture of gas and air coming into the well had ignited, and burned or melted the paraffin off the face of the sand.

I suggested that we try this on another well. We soaked waste in oil, lighted it and dropped it down, but could not get any results. We then tried sodium peroxide. For this work we selected an old well that only pumped 20 min. a day. It was about to be abandoned, and Mr. Dunn said: "It makes no difference if we do spoil this well." We dropped the sodium peroxide down in preserve jars and it was not long before we got an awful rumbling noise out of that well. A little smoke came up out of the casing.

Mr. Dunn suggested we give the well a dose of gasoline. I said I was game. So we gave the well a drum of gasoline. We could not make the gasoline burn readily, so we ran air down the well through tubing. Then the well burned vigorously but the flame would travel up and down the well according to the amount of air we gave it; at times the flame would come right up to the top. We spent the night there and had all the natives in the country wondering what we were doing with that well. In the early morning we poured in five carboys of concentrated hydrochloric acid. This made another "furor" at the bottom of the well. There were loud rumblings.

The well was then allowed to stand closed in for two weeks with the acid on the sand. At the end of the two weeks the well was put back on the pump. It pumped steadily for half a day—nothing but oil. The well produced in that way for about a month and the increased production paid many times over for the cost of the treatment. In about three months the production had declined to where it was before the treatment.

In conclusion, I would say that the trouble with chemicals seems to be that the beneficial results are only temporary. Unless the cause of paraffin deposition in wells is removed, little progress will be made in combatting the trouble. The main thing is to try to eliminate the conditions that cause paraffin troubles. Holding gas pressure on the wells may be an economical step in the right direction.

C. E. Reistle, Jr.—We found that heat generated by electric heaters was much more satisfactory than that generated by chemicals.

G. W. KNOX,* Oklahoma City, Okla. (written discussion).—For eight or more years the writer has been making research, study and demonstrations in a practical way concerning the paraffination of oil wells, and considers Mr. Reistle's paper most valuable and the best that has yet been presented. The following of his recommendations will undoubtedly go a long way toward the eradication of some of the difficulties that are being experienced in the handling of the problem.

Conditions of paraffination of oil wells are so varied, hardly any two of like character, that special study must be made of each individual case to know how best to attempt its solution. For instance, on a 15 to 20-well oil property, some of the wells will not have any trouble from paraffin, while some others will require constant effort to keep them free enough of paraffin to maintain production. With some wells having an excess of paraffin, the paraffin is of a quite soluble consistency while with another offset well it may have an extremely hard waxy consistency, even though the gas, amount of oil and other features may be like all adjacent wells. The reasons for this are perhaps to be explained by Mr. Reistle's statements regarding character of paraffins, etc.

Mr. Reistle touches upon the possible effect that water in wells has in superinducing paraffin trouble. Almost all oil operators maintain that some salt water will prevent trouble from paraffin, but this is not consistent with the experiences of the writer nor does it look reasonable scientifically. As a simple practical demonstration, take an emulsion of crude oil, paraffin and salt water; mix those ingredients thoroughly and then note how quickly there will be a complete separation of the salt water from the oil and paraffin, the salt water remaining free of any coloration or of having any perceptible suspended matter. Or again, with a gun-barrel tank receiving the pumpings from wells producing oil, paraffin and salt water, the draining water siphons out immediately, crystal white and without any coloration. Should there be a "cutting" effect of salt water on oil and paraffin, as is maintained by the average production man, is it not reasonable to believe that there would be some coloration with the draining water? It is hoped that Mr. Reistle's further research on this question will result in a better understanding of the problem.

Mr. Reistle says that in the Salt Creek oil field with the large flowing wells there was very little paraffin trouble, but as production declined paraffin trouble became more pronounced. The writer was in that field recently and was informed by an engineer of the largest operating company in the field that conditions were just the reverse; but that, however, is questionable. From observations made by the writer with about every well investigated, which were those that had declined from large production to 10 and 12-bbl. wells, the paraffination was extreme and becoming worse, according to the operators of the wells. Connected with this condition it should be stated that the amount of water made by the wells was increasing.

Of special interest is Mr. Reistle's information regarding the heating of wells with an electric heater for the removal of paraffin, which is along the lines that the writer has been working and demonstrating. The deductions that perhaps are to be arrived at from Mr. Reistle's comments are: That it is considered that the electric heater is effective for the removal of paraffin from oil wells but that the difficulties in making a suitable and lasting heater and conducting cables, together with the excessive cost of power in operating the heaters, are found so great that it is questionable about this method being considered a success, and further, that paraffin conditions being most pronounced with old wells of small production it is doubtful whether the increased production obtained by removing the paraffin will justify the expense incurred. In some respects this will be true, but with reference to the possibility and practicability of constructing suitable and lasting heaters and conductor cables for the work, the writer has proved conclusively that this can be and has been accomplished.

---

* Consulting Engineer.

The cost of the power necessary to effectively heat wells to the extent of having paying results will perhaps at this particular time run the expense so high that it will not pay to treat them electrically. However, under normal conditions, with price of oil at $2.25 per bbl. and upward, the processing of wells for the removal of paraffin will be found highly remunerative. In substantiation of this position, data are given in Table 4, from two relatively old and small wells in Oklahoma which were heated with an electric heater for paraffin trouble. The writer assisted in conducting these tests, and kept the records. The conditions were substantially as shown in the table. The wells were drilled in 1915, and were in the Bartlesville sand.

Table 4.—*Data on Wells Heated with an Electric Heater*

	No. 8 Well	No. 29 Well
Date of test	Jan. 1926	Feb. 1926
Depth of well, feet	2,875	2,828
Thickness of oil sand, feet	105	95
Points vacuum on field	26	26
Times well had been "shot"	6	2
Water well making per day, barrels	½	1
Gravity of oil, degrees Bé	41 to 42	41 to 42
Length of time well was heated, hours	72	58
Gas production per day before heating, cubic feet	2,500	Not obtainable
After heating, cubic feet	10,000	Not obtainable
Temperature of oil before heating, degrees Fahr.	84	84
After heating, degrees Fahr	160	180
Average production of well per day, barrels, before heating	7½	8¾
After heating	35	22
Number of days wells produced after heating	420	390
Total increase in production after heating, barrels	10,965	5,241
Value of increase, at $2.50 per barrel*	$27,412.50	$13,102.50

* Crude prices for the oil from these wells at the periods mentioned were running between $2.50 and $2.67 per barrel, but the lower price was used for these calculations.

The wells were heated but once, for the time indicated. Fourteen months after the heating was done, a record of the amount of production for the period stated was obtained from the owners. For a period of 11 months following the heating, No. 8 well made between 35 and 40 bbl. per day, gradually declining after that to 27½ bbl. per day at the end of 14 months. No. 29 well averaged for the same period 22 bbl. per day, declining at the end of 13 months after it was heated to 18¾ bbl. per day. The settled producing rates as given seem to hold with both wells.

The amount of power used in heating No. 8 well was 1650 kw-hr. and for No. 29 well, 1530 kw-hr., or a total power consumption for the two wells of 3180 kw-hr. At the rate of 2½ c. per kw-hr., which prevailed in this instance, the total amounted to about $80.

As a rule electric power is not available in oil fields, therefore the use of individual generating units has been resorted to by the writer, with successful results. Where it was necessary to use gasoline with which to operate the power units, the fuel cost of power per kilowatt-hour did not exceed 3 c., with a gasoline rate of 9 c. per gal. With gas available on the properties being processed, which condition usually obtains, the fuel costs are nil.

With suitable equipment for the electric heating of oil wells the additional expense to the power cost is reasonably inexpensive. Conclusions as to whether it will be profitable to electrically heat wells for paraffin trouble can be drawn from the results that have been given, although it is not intended to give the impression that in all cases such results are obtainable. However, with a careful study of conditions as to when and what kind of paraffined oil wells should be heated, the results will be justified and found profitable.

Handling Congealing Oil and Paraffin Problems in the Appalachian Fields

By Frank M. Brewster,* Bradford, Pa.

(Fort Worth Meeting, October, 1927)

The handling of congealing oils and paraffin is a serious problem in the Appalachian fields, particularly because the small amount of oil produced per well makes the removing of paraffin a very costly operation per barrel. Few operators realize or have any means of knowing just how much production is lost on account of paraffin depositing over the face of the sand and plugging the pores of the sand; but where paraffin has been removed the production increases indicate that this loss has been considerable.

Many operators believe that paraffining is confined to the tubing and pumping equipment, but it is evident that the most serious damage occurs on the face of the sand and a short distance back in the pores. This paper is an attempt to disseminate information on methods and processes in use in the Eastern fields for combatting losses of production and operating difficulties caused by deposition of paraffin in the pores, on the walls, on the tubing and on other pumping equipment. Mills[1] covers this subject so thoroughly that excerpts, abstracts and quotations from his work have been used freely in this paper.

Nature of Paraffin

Mills states: "The so-called paraffin that collects in oil wells, and in the pores of the producing sands immediately around the wells, is generally made up of amorphous wax or uncracked paraffin, asphalt, or other gummy hydrocarbons mixed with more or less water, oil and inorganic silt. Some of the samples of this 'paraffin' collected from oil wells in different fields and examined by the Bureau of Mines contains as much as 20 per cent. by weight of water and inorganic silt, whereas other samples are composed entirely of waxy hydrocarbons and oil. The inorganic silt accompanying this 'paraffin' is mostly fine sand, clayey materials, common salt and finely disseminated precipitates of calcium and magnesium carbonates. Sulfates of calcium, barium and strontium are less common constituents of paraffin."

---

* General Superintendent, Petroleum Reclamation Co.

[1] R. Van A. Mills: The Paraffin Problem in Oil Wells. U. S. Bur. Mines. *Report of Investigations*, Serial No. 2550 (December, 1923).

Principal Causes of Paraffining

1. The chilling incident to the sudden reduction of pressure and expansion of gas in the wells and in the producing sands close to the wells. (Lowering the temperature only a fraction of a degree often causes the deposition of paraffin from oil containing its full capacity of dissolved paraffin.)

2. The diminished solubility of the paraffin at the lowered pressures generally prevailing in the wells. (Paraffin is more soluble in oil and gas at higher pressures.)

3. The churning action of the pumps and sucker rods which tends to accentuate the emulsification of water, oil and silt.

4. The evaporating and drying action of natural gas. The evaporation of the more volatile constituents of the oil leaves behind the paraffin residues to be deposited in the wells and productive sands.

5. The alternate wetting and drying of the productive sand exposed in a well where the fluid level is repeatedly lowered from the top to the bottom of the sand by pumping. Expanding gas tends to chill and dry the uncovered surfaces of sand. This wetting and drying cycle is comparable to repeatedly painting the exposed faces of the sand with paraffin.

6. The leakage of certain kinds of water into wells, especially water carrying mechanically suspended silt or waters that carry dissolved salts which act chemically with the salts dissolved in other waters in the wells so as to form silty precipitates. The loss of carbon dioxide gas along with other dissolved gases from waters containing bicarbonates also causes the precipitation of silty carbonates, more especially calcium carbonate. The fine particles of silt seem to form the nuclei about which the oil and water emulsify to form some of the so-called paraffin materials.

Effects of Paraffin

Paraffin and its associated substances deposit on the face of the oil sand and in the pores, obstructing the flow of oil into the well. This damage is serious and usually goes unnoticed, as the deposition is a gradual accumulation growing progressively worse. As each well has its own individual characteristics the decline in production may seemingly be a natural decline approaching exhaustion and can be detected only by cleaning. Thus each and every well presents a different problem. However, the quantity and rapidity of deposition of paraffin in the tubing and other pumping equipment should give a very good indication of what may be happening to the walls of the hole and in the pores of the sand. The older the well, the greater is the paraffin menace as the long-continued evaporation due to the gas passing through the pores and over the face of the sand hastens the deposition of paraffin.

Naturally both gas and oil decline throughout the life of the well but generally the ratio between gas and oil increases throughout this same period. That is, the decline of gas is not as great as the decline of oil. Thus the older the well, the greater is the amount of evaporation and paraffin per barrel of oil. Hence paraffining is an accumulating evil that may plug off the pores in the sand long before the well is exhausted by present production methods.

Casing, tubing and pumping equipment are subject to paraffining but the damage is not as serious as paraffining of the sand. These troubles are readily apparent and can be remedied, but at considerable cost.

The Forest Oil Corpn.[2] has kept its records of paraffin troubles and found that 9 per cent. of its pumping and pulling troubles were due to paraffin. The percentage of paraffin trouble was kept to a minimum by frequent turning of the rods just as the tubing was filling with oil. (These wells are in the Bradford, Pa., and Allegheny, N. Y., water-flood areas and pump considerable water with the oil.)

Dr. Garner,[3] of the Hope Natural Gas Co. and affiliated companies, estimated that 50 per cent. of their production troubles were due to paraffin and that most of these troubles were in the well and not in the pumping equipment.

Mr. Goe[4] states: "I have had very little paraffin trouble in tubing for the last 20 years, or since I began the use of wire lines for pumping instead of rods. The action of wire lines in tubing keeps the paraffin cut and it is pumped out with the oil into the tanks."

Methods of Preventing Paraffining in Well

Several methods of preventing the deposition of paraffin in the pores and on the face of the sand have been used with partial success, but in practically all cases the paraffining has been retarded and not prevented. Two methods are in general use; both back-pressure methods. One is to keep the sand covered at all times with oil; the other is to hold a back-pressure on the sand by partially cutting off the flow of gas from the well.

Back-pressure

Back-pressures as high as possible without materially curtailing production should be held at all times on a producing well. This diminishes chilling by lessening the expansion of gas and evaporation of the lighter constituents as the oil and gas enter the hole. Also, at higher pressures

[2] Forest D. Dorn, president, Forest Oil Corpn., Bradford, Pa. Personal communication, August, 1927.

[3] J. B. Garner, director chemical and engineering research, Hope Natural Gas Co., Pittsburgh, Pa. Personal communication, July, 1927.

[4] H. M. Goe, superintendent, Hope Construction & Refining Co., Parkersburg, W. Va. Personal communication, July, 1927.

more paraffin is retained in solution. Back-pressures may be held by a high fluid level maintained in the well or by closing or partially closing the casinghead or by a combination of both. Keeping the sand covered not only keeps the paraffin in solution, or at least in suspension, but also prevents exposure of a dry surface to which the paraffin can adhere, and the paraffin is readily pumped into the tubing. Where water is produced with the oil, it is necessary to put the perforations near or below the bottom of the sand and to place the working barrel at the top of the sand or at some distance above it, to maintain a desired back-pressure. A flood nipple placed just beneath the working barrel prevents exposure of the sand and the perforations at the bottom serve to keep the water off the face of sand.

Methods of Removing Paraffin from Well

Several methods of removing paraffin from the face of the sand and out of the pores adjacent to the wells have been tried with partial success. No completely satisfactory method has as yet been devised but a few methods give promise of successful development. These are: cleaning out, shooting, reaming the sand, the use of solvents such as gasoline, benzol, etc., heating and melting by steam, hot water, hot solvents and chemicals and by burning with chemicals or combustible mixtures introduced and ignited opposite the face of the sand.

Cleaning Out

Cleaning out with tools removes loose sand, slate, muck or other materials that have fallen into the hole but it does not to any great extent remove the paraffin from the face of the sand or its pores. Cleaning out with high-pressure air or gas does reach the walls of the hole and tear off any loose particles but it also has a tendency to plaster over the face of the sand and drives soft materials into the pores and fissures, thus defeating its purpose. Present methods of cleaning out must be supplemented by other methods or agents if paraffin is to be completely removed.

Shooting

Shooting after a well has been cleaned out has been very successful in melting and burning paraffin off the face of the sand. In addition, it breaks down the walls of the hole, exposes fresh rock and opens new fissures and fractures. Too heavy and frequent shooting causes excessive caving with long drawn out cleaning jobs. Successively larger shots are necessary to be effective on account of the increasing size of the hole. In soft sand very small shots should be used as there is danger of driving paraffin back into and packing the sand. But the main objection to shooting is the cost. Each successive shot is necessarily larger and more

costly and at the same time the production increases are smaller. Shooting is also limited to wells that have no casing near the shot, because there is danger of bursting or collapsing the casing.

Reaming

In conjunction with cleaning out, several devices for reaming the sand have been made and successfully demonstrated but they have not been used to any great extent in the Eastern fields, probably because of cost and lack of adequate surface equipment. This principle and method of cleaning is highly desirable, as the cleaning can be confined to any particular part of the sand needing cleaning and the size of the hole can be controlled at will.

Solvents

Gasoline, benzol, kerosene and crude oil have been used to dissolve paraffin. Gasoline does not readily dissolve paraffin, so the common practice of dumping two or three drums of gasoline down the well attains only partial success. Kerosene and crude oil also exert a solvent action on paraffin but are only slightly better than gasoline. Benzol is a better solvent than any, but the general use of these solvents is too costly for the partial success obtained. Heating any of the above solvents by steam, hot water or other methods increases their solvent action but they must be circulated, as they may melt and dissolve the paraffin only to carry it back into the sand and redeposit it on cooling. Hot solvents should be bailed or pumped out while still hot. By circulating for several hours very good results can be obtained from the use of solvents. The solvent as pumped out should go through a cooling tank to deposit the excess paraffin and then be reheated before returning down the casing.

Steaming

Steaming is a common practice for melting paraffin off the sand and for cleaning tubing, especially where boilers are available, but steaming is generally too costly and is not satisfactory for cleaning the sand. However, it is one of the quickest and cheapest ways of cleaning tubing. The usual procedure is to turn steam down between the tubing and casing. This melts the paraffin off the tubing and it is easily pumped out. The steam usually condenses before reaching the bottom of the hole and the hot water is pumped out with the oil and melted paraffin. This method is hazardous, as usually the steam is confined to the casing-head under pressure and the pressure may be great enough to force the melted paraffin back into the sand, thus making conditions worse. A better method is to run a string of 4-in. outside the tubing and to a depth below the working barrel. Steam can be run down between the tubing

and 4-in. and back under no pressure to the surface. This permits continuous pumping while heating and applies no pressure on the sand. The heat melts the paraffin and the flow of oil into the hole washes it from the sand.

Where boilers are not available, a crude method is to heat iron billets and lower them into the hole. This method is slow and where the shot hole is large it is almost an endless task to heat the fluid in the hole hot enough to do much good. It is also a dangerous practice, as gas from the well may be ignited by the hot billets as they are put into the well. A much cheaper and more satisfactory method would be to lower hot solvents in a dump bailer.

Chemicals

The practical value of chemicals[5] and solvents depends on their cost. They are very satisfactory but their cost is usually prohibitive. Calcium carbide in sufficient quantity and used with water generates ample heat to melt paraffin.

Caustic soda (sodium hydroxide) and metallic aluminum on contact with water generate considerable heat. This combination was used quite extensively in the Eastern fields but it is a patented process and operators are reluctant to pay the premium. Also, in general, they have used too small a quantity for satisfactory results.

Sodium peroxide, 100 lb. or 200 lb. dumped in wire cloth, tin, or glass containers into 1 or 2 bbl. of water, generates intense heat and liberates oxygen to support combustion. Hydrogen and oxygen are generated through decomposition of water and they also burn. The paraffin is removed both by melting and burning. This process has not been used extensively, but increases of 50 to 100 per cent. in production have been reported. However, this reagent on contact with water or damp objects immediately ignites and is dangerous to ship, handle, or use around inflammable structures.

Hydrochloric acid, when used to follow up sodium peroxide, gives another violent reaction and generates intense heat. It also dissolves any calcium carbonate that may be in the well. Calcium carbonate is just as objectionable as paraffin for plugging up and coating the pores in the sand and it is usually present in wells having a lime cap rock or lime interspersed with the sand. The fluid resulting from the hydrochloric acid reaction can be left in the well for several days without damage but where paraffin is prevalent it is advisable to bail while hot.

Sulfuric acid with caustic soda and water has been used quite extensively. It generates considerable heat and has been successful in removing paraffin, but it is dangerous to use in wells containing calcium

---

[5] R. Van A. Mills: *Op. cit.*

or barium, as it reacts with them to form insoluble sulfates commonly called "gyp," which may plug the pores in the sand.

Combined Use of Solvents and Reagents

Gasoline, benzol and other solvents can be heated in the hole by using some of the above-mentioned reagents and the success of both processes may be materially increased, but the fluid should be bailed or pumped out while hot.

Burning

A comparatively cheap and effective method of removing paraffin has been developed by the Hope Natural Gas Co. It is called the Garner-Leyden[6] process (patented) and consists of maintaining a flame at the bottom of the well. A combustible mixture of air and gas are introduced through the tubing during the process of burning. This combustible mixture is ignited opposite the face of the sand by lowering a fusee between the casing and tubing. Temperatures between 2300° and 2700° F. are maintained as long as desired. This melts and burns the paraffin. The following examples[7] are representative of results obtained by this process:

"Case *A*.—Production in this well had declined to 6 bbl. per month in September, 1922. Heat treatment was used late in October and the well produced as follows: October, 1922, 14 bbl.; November, 17 bbl.; December, 19 bbl.; January, 1923, 18 bbl.; February, 11 bbl.; March, 15 bbl.—a net gain of 64 bbl. in five months. The well is now (January, 1925) making 11 bbl. per month.

"Case *B*.—Before burning, the well made 4 bbl. oil per month. It was burned Nov. 12, 1922, and a partial record is as follows: November, 1922, 2 bbl.; December, 5 bbl.; January, 1923, 12 bbl.; February, 7 bbl.; March, 7 bbl.; making a net gain of 15 bbl. in five months. It is now (January, 1925) producing 7 bbl. per month.

"Case *C*.—This well had not so nearly reached the exhaustion stage as the ones previously cited. It had declined to 25 bbl. in October and 24 bbl. in November, 1922. Heat treatment was applied Dec. 16, 1922. In December, 1922, the production was 77 bbl.; January, 1923, 60 bbl.; February, 67 bbl.; March, 42 bbl. This represents a net gain of 146 bbl. in four months. The well in October, 1925, was still producing 45 bbl. per month.

"Case *D*.—This well averaged about 11 bbl. of oil per month to January, 1923. In January it produced 8 bbl., February, 10 bbl. New rig had to be built and liner fished out. In March the well produced 17

---

[6] J. B. Garner: Personal communication, Aug. 1, 1927.

[7] *National Petroleum News* (Jan. 28, 1925); confirmed by Dr. J. B. Garner. Personal communication, Aug. 1, 1927.

bbl. of accumulated oil. In cleaning out oil was mudded and paraffined off entirely from March 30 to April 11. On April 11 the well was burned for 1 hr., 20 min. On April 12 the well was swabbed for 11 bbl., leaving about 10 bbl. fluid in hole. It is now (January, 1925) producing 18 bbl. per month.

"Case *E*. —At the middle of April, 1924, this well was producing at the rate of 50 bbl. per month. The $5\frac{3}{16}$-in. was pulled to shoot, letting water on the oil, and the well was shot with 50 qt., mudding off the oil. Steam was used in the endeavor to bring the oil back, without results. The well was burned about June 1, the well showing for less than 1 bbl. per day at that time. It is now (January, 1925) producing 100 bbl. per month."

It can be seen from these cases that paraffin in the pores and on the face of the sand had caused a serious loss in production. Dr. Garner further states (letter of August, 1927) that 50 per cent. of their well trouble is due to paraffin. The Garner-Leyden process can be cheaply applied in wells producing an excess of air on properties using the air-recovery process. Oil-soaked waste which has been ignited is dropped down the well and burning takes place on the face of the sand. It is usually allowed to burn for about 24 hr. and then extinguished by pouring water down the hole. A similar method where compressed air is available is to pour about one barrel of gasoline down through the tubing and follow by compressed air. Ignited oil-soaked waste or a fusee is then dropped down the outside of tubing. To extinguish this flame it is only necessary to shut off the air.

Paraffin in Pumping Wells

Wells pumping by heads are usually more pronounced in their paraffin troubles. In this case the oil is flushed from the tubing, leaving a thin film from which the paraffin settles out on the tubing and rods. This partially dries out and becomes firmly attached to the rods and tubing. Thus every flushing applies another coating and the accumulation of paraffin is relatively rapid. This same trouble occurs in wells pumping part time and where the equipment, valves or tubing leak.

When paraffin is permitted to dry out or partially dry out, it firmly attaches itself to any surface exposed and this paraffin is not redissolved or loosened when again flushed with oil. As long as the tubing or sand is full of oil the paraffin remains dissolved or is held in suspension; it does not firmly attach itself to objects but settles very slowly to the bottom.

Cleaning Tubing

The most practical and cheapest method of cleaning tubing or casing is by the use of the "paraffin hook."

"The paraffin hook[8] consists of a shaft on which is placed a disk of the same diameter as the inside diameter of the pipe to be cleaned. This disk is usually made from old belting and is reinforced by a metal disk slightly smaller in diameter. The shaft is so shaped that the disks are held in a diagonal position while being lowered into the casing or tubing but slips down into a horizontal position when pulled from the well, thus scraping the paraffin off the casing or tubing in coming out. The shaft is made with a tool joint for casing and sucker-rod joint for tubing. A sinker bar and jars are used for forcing it down the casing while a polished rod or sucker rods are used to force it down the tubing.

"This tool removes the paraffin from the well instead of merely cutting it from the pipe. This feature makes this tool valuable for use in wells where the paraffin has completely plugged the pipe or where the deposit is hard and extensive. In removing large deposits the tool should be run several times, taking only a part of the deposit each time in order to prevent overloading."

By using the paraffin hook whenever the rods are pulled it is possible to keep the tubing comparatively free of paraffin. It requires about 2 hr. to thoroughly clean 500 ft. of tubing. The use of a small winch or tractor or truck for pulling rods and running the hook or swab is very economical.

Conclusion

Present methods of removing paraffin from the face of the sand and out of the pores are not entirely satisfactory. The cost is very high and the beneficial results are usually short-lived, as generally within a few months production has declined to the level preceding cleaning. However, the Garner-Leyden process of burning is exceptional in that it has given an increase of production which has continued over a period of four years.

The use of chemicals as a whole is unsatisfactory. The heat generated is insufficient to cause the melting of an appreciable amount of paraffin, and if larger quantities of chemicals are used the cost becomes prohibitive.

Solvents are better than chemicals for removing paraffin but to get satisfactory results it generally is necessary to heat and circulate the solvent for several hours. Also, in deep wells and large shot holes the quantity of solvent necessary for satisfactory results makes the cost a considerable item.

In most cases, the removal of paraffin by burning or hot solvents has been the more satisfactory. For cleaning tubing, casing, and pumping equipment, mechanical means are by far the better method.

[See also Round Table Discussion, page 392.]

[8] C. E. Reistle, Jr.: Removing Paraffin from Flowing Wells. U. S. Bur. Mines *Reports of Investigations*, Serial No. 2802 (April, 1927).

Handling Congealing Oils and Paraffin in Salt Creek Field, Wyoming

By F. E. Wood,* Casper, Wyo., H. W. Young† and A. W. Buell,† Midwest' Wyo.

(Fort Worth Meeting, October, 1927)

This paper summarizes the results of laboratory tests conducted to determine the properties of the paraffin or rod-wax encountered in the Salt Creek field, Wyoming. It also describes field tests and methods employed to cope with the paraffin problem. The conclusions to be drawn from the laboratory work are:

1. Samples of Salt Creek paraffin range in consistency from soft to hard, the melting points varying from 120° to 156° F.

2. Masses of soft paraffin are soluble to an appreciable extent in crude oil and its liquid fractions at temperatures somewhat below the melting point of the paraffin. Hard paraffin is very slightly soluble under these conditions.

3. Agitation apparently increases the amount of paraffin that will go into solution.

4. Paraffin congeals from solutions upon cooling to the point of saturation, which is in all cases below the melting point of the paraffin.

5. Crude oil is the most effective of all the solvents for holding paraffin in solution.

6. Pressure alone does not appreciably affect the solubility of paraffin in crude oil nor does it aid materially in holding paraffin in solution when the temperature is reduced.

7. Natural gas in solution under pressure does not appreciably increase the solubility of paraffin in crude oil, but is effective in holding paraffin in solution when the temperature is reduced.

8. A foreign body introduced into a solution of paraffin in oil is immediately coated with paraffin if the temperature of the solution is at or below the melting point of the paraffin, and the object is considerably cooler than the solution.

It may not be entirely correct to say that paraffin is taken into solution; it is impossible that the paraffin may be in suspension rather than in solution.

---

* Petroleum Engineer, Midwest Refining Co.

† Research Engineer, Midwest Refining Co.

The object of the laboratory investigation was to determine the conditions favorable for dissolving paraffin and for preventing its deposition from crude oil.

As noted above samples of Salt Creek paraffin graded from soft to hard. Soft paraffin contains a considerable amount of oil whereas hard paraffin has suffered loss of oil by evaporation and drainage.

Method of Testing

Compact masses of paraffin grading from soft to hard were placed in beakers containing gasoline, kerosene, naphtha, crude oil, and mixtures of these liquids, and maintained at temperatures varying from 50° F. to the melting points of the paraffin for intervals varying from 1 to 24 hr. The amount passing into solution was measured by weighing the samples before and after treatment. Below 100° no measurable solution occurred; above that temperature the soft paraffins began to dissolve to some extent, and were appreciably soluble at temperatures somewhat below their melting points. No weighings were made in tests in which the temperature exceeded 100°, as the masses of paraffin softened and in part disintegrated. The samples of hard paraffin did not disintegrate and dissolve appreciably except at temperatures only slightly below their melting points.

No quantitative tests were made to determine the effect of agitation. Agitation would undoubtedly increase the tendency of the masses of paraffin to disintegrate, thus exposing more surface to the solvent.

Solutions containing 5, 10, 15 and 25 per cent. by weight of paraffin in crude oil were prepared by heating to temperatures above the melting point of the paraffin and were allowed to cool. At 100° practically all of the 25 per cent. solution and over 40 per cent. of 15 per cent. solution had congealed. At this temperature there was only a slight deposition in the 10 per cent. solution and none in the 5 per cent. solution. Dropping the temperature to 60° increased the deposition somewhat in the 10 per cent. solution and caused a slight deposition in the 5 per cent. solution. Parallel tests with the other solvents proved that these were not nearly as effective as crude oil for holding paraffin in solution.

Effect of Mechanically Applied Pressure

Tests were made to determine the effect of mechanically applied pressure upon the solubility of paraffin in oil and also the effect on the capability of the oil for retaining the paraffin in solution. A ball of paraffin was introduced into crude oil and a pressure of 250 lb. was applied. After standing under pressure at 100° for several hours the paraffin ball was removed and found to have lost no weight.

Oil samples containing 5, 10, 15 and 25 per cent. of paraffin were prepared and a pressure of 250 lb. was applied to all except the last, which congealed too rapidly to permit it being introduced into the pressure apparatus. The container filled with the sample was placed so that it could be emptied without reducing the pressure, by inverting the apparatus. The apparatus was cooled to 100°, inverted and opened; the amount of congealed paraffin remaining in the container was found to be the same as in the corresponding tests at atmospheric pressure.

Other experiments were performed to determine the effect of natural gas dissolved in oil under pressure on the solubility of paraffin. A ball of paraffin was placed in oil saturated with gas at a pressure of 160 lb. and maintained for several hours at a temperature of 100°. Upon removal, the paraffin ball showed no loss in weight, indicating that no solution had occurred.

Effect of Gas under Pressure

Another series of oil samples containing 5, 10, 15 and 25 per cent. of paraffin was prepared. These were saturated with gas at a pressure of 160 lb. while heated to a temperature sufficiently high to insure solution of all paraffin. The beaker containing the solution was held in such a way that the apparatus could be shaken to facilitate the absorption of the gas without emptying the beaker. The solutions were then cooled to 100° and permitted to stand under pressure for several hours. The apparatus was inverted to permit the uncongealed solution to flow from the beaker while saturated with gas under pressure. When the apparatus was opened, the 5 per cent. and 10 per cent. samples showed no deposition of paraffin in the beaker, while the 15 per cent. sample showed only a very light deposition. The 25 per cent. solution showed only a light deposition and did not solidify until most of the dissolved gas had escaped. Comparing these results with those in which no dissolved gas was present proves conclusively that dissolved gas aids in holding paraffin in solution

Paraffin Deposition in Wells and Flow Lines

An interesting feature brought out in these experiments was that any foreign body, such as a thermometer, glass rod, or a piece of pipe, if at a temperature considerably lower than the oil, was immediately coated with paraffin when introduced into the oil samples containing the higher percentages of paraffin, provided the temperature of the oil was not higher than the melting point of the paraffin. This property, together with the loss of gas from solution, helps to explain the deposition of paraffin in tubing, flow lines, etc.

Methods of Preventing or Removing Paraffin

In the Salt Creek field various tests and methods have been tried to relieve paraffin deposition in oil wells and flow lines. The zone of maximum paraffin deposition, which was at first in the surface lines at a distance from the well, has migrated to the casinghead, down the tubing, and is now below the standing valve and may even be in the surrounding sands.

Steam and Gas in Surface Lines.—In the early productive life of the Salt Creek field flow lines were cleaned throughout the year by steaming them or applying high pressure gas. Recently this method has been used only during the colder months.

Paraffin Hooks.—A swab or paraffin hook has been used to clean casing or tubing. This method is discussed in detail in a paper by Reistle.[1]

High-pressure Pops.—Pops releasing at 75 lb. were placed on the flow lines at the tank batteries in certain districts during the period of heavy deposition of paraffin in these lines. The greatly reduced deposition under these conditions was undoubtedly due to the paraffin being held in solution by the increased amount of gas in solution in the oil.

Electric Heaters.—Electric heaters have been tried in certain wells. In wells producing 30 bbl. or more per day there has been no appreciable increase in production whereas in some of the smaller wells increases varying from 50 to 800 per cent. have been reported. Since this work is still in the experimental stage it can not be definitely stated that the increase has been due to the removal of paraffin from the face of the sand, as it may have resulted from the reduction in viscosity of the oil due to increase in temperature. Electric heaters have been described by Peake and Prior[2] and by Reistle.[3]

Steaming.—Experiments were conducted to determine the effect of steaming wells at high temperatures and pressures. Steam was introduced into the well from a Baker boiler capable of delivering steam to the casinghead at 1000 lb. pressure and 1100° F. The wells were tubed with a regular pump string and the steam was introduced through a ¾-in. line within an auxiliary 2-in. string which served as a heat insulator. The lower end of the ¾-in. tubing was plugged, with perforations immediately above to direct the steam against the walls of the well. Oil, condensed steam, sand, and basic sediment were pumped from the well while steaming was in progress. The steam was delivered at the casinghead for 8 to 16 hr. at pressures varying from 700 to 1000 lb. and temperatures varying from 700° to 1100°. Maximum thermometers and

---

[1] U. S. Bur. Mines *Report of Investigations*, Serial No. 2802.

[2] See page 194.

[3] See page 227.

sealed glass tubes containing salts of known melting points were placed near the bottom of the pumping string. The temperature of the pumped fluid at the casinghead was recorded during steaming and was found to approximate 200°. The temperatures at the bottom of the hole averaged 200° to 220°. This process has proved more adaptable to wells suffering from mud conditions than those which appeared to have paraffin trouble.

Thermit.—Thermit shots were employed on a number of wells with no apparent increase in production, with one exception. Thermit consists of an intimate mixture of powdered aluminum and ferric oxide, which, when ignited, form aluminum oxide and metallic iron, the temperature of the reaction being approximately 5000°. The method of handling the shot is similar to that used in shooting with nitroglycerin. The temperature at the bottom of the well was increased to only 120°, which was not sufficient to melt the paraffin.

Hot Water.—Forty barrels of boiling water were introduced into the casing of a well. In dropping from the surface to a depth of 1900 ft. the water cooled to 114°, indicating that boiling water cannot be introduced at the surface and reach the sand at a temperature sufficiently high to melt paraffin. By circulating hot water the temperature at the sand might be raised to the melting point of the paraffin.

High-pressure Gas.—Experiments have been conducted with gas under 200 to 300 lb. pressure. This gas was introduced through the tubing and returned through the casing. While a considerable amount of material was blown from the well, there is no record of any increase in production as a result of this treatment.

Reflux Gasoline.—Before the laboratory work on paraffin was completed a non-commercial grade of very highly volatile gasoline from the weathering plant at the Midwest gas plant was introduced into the wells between the casing and tubing. No increase in the production followed this treatment. After the laboratory work was completed this practice was discontinued, as it was established that gasoline at ordinary temperatures would not dissolve a sufficient quantity of paraffin to be of any practical value.

In summing up the results of the experiments outlined, the conclusion is that the electric heater has proved the most effective in increasing oil production. It cannot be said, however, that experiments that have been unsuccessful in the Salt Creek field will not alleviate troublesome conditions in other fields.

DISCUSSION

K. B. Nowels,* Laramie, Wyo.—For the past three years the Bureau of Mines station at Laramie, Wyo., has carried on extensive investigations of paraffin problems with particular reference to solubility. The findings are not quite ready for publica-

* U. S. Bureau of Mines.

tion, but the work has shown that solubility of paraffin exists in crude oil. I will ask Mr. Reistle to give us a few facts.

C. E. Reistle, Jr.,* Laramie, Wyo.—The manner in which we determined this is interesting. The first thing we decided from analysis was that the soft paraffin and hard paraffin was a matter of the oil content. We got the same melting point from them after removing the oil.

We took the wax and ground it up in a meat grinder; put it in a solubility bomb and the latter in a temperature bath. While there the container was shaken mechanically. Then this was put into a centrifuge at the same temperature and left there 10 or 15 min. to insure precipitation of any suspended paraffin. It was then put into a weighing bomb and the gasoline was taken out; what remained we took to be paraffin.

We showed that paraffin wax was soluble to a certain extent at 100°. We conducted the same tests with lumps of crude paraffin, in some cases sloughing off and in some not.

Determining the amount of paraffin in crude is a hard proposition, as paraffin has a tendency to absorb oil. If a sample were put in oil, it would be a different product when taken out. We are not using ethylene dichloride as a solvent, which holds the oil in solution. We analyze the amount of wax in the oils and know we get out the same amount of paraffin that we put in. We are not making a complete study of the Salt Creek field.

W. V. Vietti,† Ponca City, Okla.—In some of our wells which have been operated to produce crude of 38° gravity, the oil deposits paraffin in flow tanks which must be cleaned out every month. We have changed operating conditions of the wells and raised the gravity to 40 or 41, and the paraffin has disappeared from our tanks. This shows that paraffin is soluble in crude oil or gasoline, since we merely increased the gasoline content of the original crude.

In Mr. Wood's experiments, he put the paraffin in the bottom of the vessel; for the primary solution of the paraffin in the oil he depended on the natural solubility of the paraffin in the film of oil surrounding the paraffin. Solution of paraffin from there on depended upon the diffusion of paraffin through the saturated layer to the oil outside the film. We know this diffusion will be slow.

Experiments that have been performed on the diffusion of gas into oil show that this is a very slow reaction. We naturally assume that the diffusion of paraffin would be slower than of methane and ethane. Therefore it seems that Mr. Wood's experiments have not been conclusive, since the phenomenon measured was diffusion and not solubility.

F. E. Wood.—I agree entirely that with the necessary time and agitation small amounts of properly prepared paraffin will dissolve in organic solvents in the laboratory at temperatures below its melting point. The quantity of Salt Creek paraffin, however, that dissolves at the lower temperatures is so small in comparison to the large amount of necessary solvent that its application to wells for removal of paraffin is impractical. And further, preparation of the paraffin in the hole preliminary to introduction of the solvent and agitation of the mixture after the solvent has been introduced are not feasible.

B. R. Stevenson,‡ Ponca City, Okla.—We have used liquefied gases on an experimental scale as a solvent for paraffin. Last year I took some paraffin that had been cleaned out of a well, placed it in a bomb and then ran in some liquid gas under pres-

---

* U. S. Bureau of Mines.

† Marland Oil Co.

‡ Marland Refining Co.

sure. After allowing the bomb to stand for a few hours without shaking, I opened the valve and let the gas blow out. Much of the paraffin came out with the gas as a fine white powder, showing that it had been dissolved and held in solution until the liquid gas was vaporized. This experiment seems to indicate that oil with the vapors held in solution will hold more paraffin than without the vapors, and also that these usually waste vapors could be used to dissolve the paraffin in a well.

W. V. Vietti.—In getting wells ready for repressuring operations we have applied pressure up to 500, 600 or 700 lb. at the well head without the well taking much gas. We then lubricated in several barrels of gasoline and were able to put considerable air in at several hundred pounds less pressure. After the gasoline was introduced, it was sloshed around by alternating pressure on well head and tubing or by alternate pressure, and thus dissolved out the obstructing material of waxy deposits.

C. V. Millikan.—I would like to ask Mr. Wood regarding the temperature after shot in the case he mentioned. How much glycerin was used?

F. E. Wood.—The normal temperature of the formation in the well tests is 100° F. After shooting 14 ft. of sand with 20 qt., the temperature increased to 135° F.

Problems Encountered in Handling Panhandle Crude*

By William Victor Vietti, Ponca City, Okla., and William A. Oberlin, Fort Worth, Texas

(Fort Worth Meeting, October, 1927)

Crude petroleum produced in the Texas Panhandle oil field is both an asphalt and a paraffin-base oil and is further characterized by being a high-gravity crude with an extremely high cold test. An eight-well composite of Panhandle crude showed the following characteristics:

Gravity, 36.6° A. P. I.
Viscosity: 61 sec. Saybolt at 100° F.
170 sec. Saybolt at 75° F.
1560 sec. Saybolt at 50° F. (stirring)
Cold Test, 60° F.
Distillation Test:

	Per Cent.		Per Cent.
Gasoline	28.8	Wax	19.2
Kerosene	4.8	Asphalt	13.0
Gas oil	30.7	Sulfur[1]	0.8
Fuel oil	34.7		

Subsurface Conditions

The original pressure in the formation in the Panhandle field closely approximated 420 lb. gage or 435 lb. absolute pressure. Temperatures taken indicate that the formation temperatures do not exceed 90° F. The temperatures in Table 1 are typical measurements taken on one lease.

Table 1.—*Temperatures in Panhandle Wells*

	Oil Production, Bbl.	Gas Production, M. Cu .Ft.	Temperature 5 ft Off Bottom, Deg. F.	Temperature 10 ft. Off Bottom, Deg. F.	Temperature Top of Liner, Deg. F.	Temperature at Surface, Deg. F.
Well No. 1	120	1000	86.5	86	74	65
Well No. 2	210	5000			67	60
Well No. 3	450	2500			73	62
Well No. 4	410	3500			68	62

* A contribution from the research department of the Marland Refining Co. of Oklahoma and the production engineering department of the Marland Oil Co. of Texas.

[1] Smith [Analysis of Panhandle and Big Lake Crudes. U. S. Bur. Mines, *Circular* No. 6014 (December, 1926)] found an average sulfur content of 0.6 per cent.

Both pressures and temperatures are subnormal for the average depth (3000 ft.) of the oil formation.

The effect of the gas expanding from the formation pressures to well and atmospheric pressures is shown very clearly by these results. The casings in wells Nos. 1, 3 and 4 were cemented above the pay; well No. 2 was not cemented. Some free gas was encountered in a formation above the oil pay and is not cased in wells Nos. 1 and 3. The gas entering the well in wells Nos. 2 and 4 comes through the liner, presumably from the upper gas, by means of a connection through the formation back from the well, or from a gas sand immediately above the pay. The point of entry of the gas into the well is clearly pointed out by the temperature measurements, and is at the top of the liner in wells Nos. 1 and 3, and through the liner in wells Nos. 2 and 4.

Occurrence and Handling of Paraffin

The separation of paraffin from Panhandle crude is localized almost entirely in the flow string. The amount of paraffin formed varies with each well, but can generally be said to increase with increased gas and decrease with increased oil production. Flow strings, when pulled out of a flowing well (which is flowed by gas entering under the casing), exhibit small amounts of paraffin down to 800 ft. Between 800 and 1200 ft. the paraffin thickened, and if not cleaned out, plugged the flow string in this section. From 2000 ft. down, the paraffin gradually disappears and the last few joints are practically free from paraffin. Paraffining occurs from the point of entry of gas up to 800 ft. from the surface, and even to the surface when excessive amounts of gas are produced with the oil. The separation of paraffin seems to be controlled by the cooling caused by gas expansion.

Swabbing wells show a general paraffin condition throughout the casing. This is due to the swab carrying paraffin on both downward and upward travel. The swab will shove paraffin ahead of it on the down stroke and unless a vigorous head follows the swab, this paraffin tends to collect below the casing, restricting the hole area and also coming in contact with the oil pay. The paraffin collected below the casing gradually decreases the production of a well. It is cleaned out by the use of a string of tools and is often supplemented by the use of gasoline and kerosene. The swab with the check valve removed is used at first in flowing wells to clean out the paraffin collected in the casing. As a general rule, the frequent running of a swab in a flowing well handles the paraffin satisfactorily.

Infrequent or non-use of the swab results in the paraffining of the pay, and a large decrease in production. A comparison in this respect

is available in the granite wash area. One well, 960 bbl. initial production, was cleaned of paraffin by running the checkless swab twice a day. This well was still producing 425 bbl. one year after completion. Another well, in an adjoining lease, came in for 1200 bbl. This well was allowed to flow until the paraffin plugged the casing. It was cleaned out with tools, using 60 bbl. of gasoline to hasten the process. This was repeated twice, using 90 and 120 bbl. of gasoline, respectively. Production was much smaller after each clean-out, and after the third clean-out the well was flowing 100 bbl. daily. This well is now a small producer, making around 25 bbl. daily. There is no doubt that the paraffin was driven into the formation by the action of the tools. This could have been avoided by cleaning the casing of paraffin every day, or every other day. A study of paraffin conditions in each well determines whether the swab should be run twice a day, daily or even weekly.

Effect of Gas-lift and Flowing through Tubing

The gas-lift, and the practice of flowing through tubing, have considerably reduced the use of the swab and its attendant evils in the Panhandle. Different conditions were imposed on the wells, and to meet these better tools were devised to handle the paraffin. A paraffin cutter or "flow devil," was designed by N. O. Miller[2] to eliminate the use of the swab in flowing wells. This tool was adapted to use in tubing. It cuts out the paraffin, which is then flowed up the casing and out into the stock tank, through the annular opening by the flow of oil and gas. By its careful use paraffin is removed as fast as it is cut. Gas-lift wells, flowing pipe-line oil, show paraffin forming in the tubing, 1500 to 2000 ft. off bottom to the surface, as in the flowing wells. Wells making water on the gas-lift deposit paraffin from the bottom of the tubing to the surface. Gas-lift wells flowing high percentage of water show no paraffin formation. One of the gas-lift wells flowing 80 per cent. water has been flowing two months without any noticeable paraffin formation.

Kerosene as Paraffin Solvent

Kerosene has been used as a solvent for paraffin, with some success in increasing production. The results given in Table 2 are typical after lubricating from two to six drums of hot kerosene in wells which had

---

[2] For a full description of this tool and a discussion of its use, see Some New Aspects of the Gas-lift, by E. O. Bennett and K. C. Sclater, Petroleum Development and Technology in 1926, 115.

See also C. E. Reistle, Jr.: Removing Paraffin from Wells. *Oil & Gas Jnl.* (May 12, 1927).

shown rapid decline in production two to three days previously. The kerosene dissolved the paraffin obstructing the passage of oil, and the production regained, or surpassed, its normal value.

TABLE 2.—*Effect of Kerosene Wash on Production*

Well No.	Average Daily Production for One Week			
	Method of Production	Before Lubrication	After Lubrication	Daily Increase
1	Gas-lift	90	97	7
2	Pump	60	88	28
3	Gas-lift	130	145	15
4	Pump	30	60	30

Kerosene has also been found useful in reducing operating pressures in gas-lift wells. Gas-lift wells will show a gradual increase in operating pressure, which cannot be accounted for except by the accumulation of paraffin at and near the bottom of the tubing, both in the casing and in the tubing. The lubrication of a few drums of kerosene into wells of this type reduces operating pressures 10 to 40 lb. to its original value.

A method of eliminating paraffin, that has collected in the pay formation is to allow the well to stand for a few days. If the well is not gassing, the face of the well bore is warmed by conduction from the formation adjacent to the well to temperatures approaching the original subsurface temperatures, and the warm oil is given an opportunity to soften and dissolve the paraffin. This has been tried and has given excellent results. A well on the gas-lift which had decreased in production was shut in for four days. The average production for two weeks before shutdown was 45 bbl.; after the shutdown the production increased to 130-bbl. average.

Pumping wells cause much trouble because of the separation of paraffin in the pump and in the tubing. Valves stick, friction is increased and pump action becomes jerky and erratic. This has caused much rod breakage, and the pulling of tubing and pump to steam out the paraffin. Some of these difficulties have been overcome by lubrication of kerosene into the well and by the introduction of steam, either through the casinghead or by means of a string of small tubing 100 to 1000 ft. long.

USE OF WIRE-LINE PUMPS AND HEATERS

Increased mechanical efficiency and increased production have resulted from the use of wire-line pumps. The whip in the wire line keeps the paraffin from collecting in large amounts in the tubing. Breakage of the wire line is less than the previous breakage of rods. When the wire-line pumps were first used, wire-line breakage was severe. The

field men noted that the breakage occurred at the wire-rope socket connecting the wire rope to the short length of sucker rod between the pump and line. A study was made and the conclusion was reached that the breakage occurred because the wire line was falling faster than the pump barrel, and the resulting bend broke the line. Now, 300 ft. of sucker rod are attached to the top of the pump, and the added weight and rigidity have partially eliminated this breakage. This defect has been further eliminated by slowing down the pumping stroke to 18 s. p. m. and pumping in the fourth hole to offset the decrease in pump capacity due to slower motion. This slower motion allows the pump to drop at a rate comparable to the pumping motion. Production has increased 10 to 30 bbl. on each well where this has been tried. Increased production is also due to the installation of electrical motors, with the resulting evenness of operation. The wire-line pump, however, is still causing much trouble, by breaking of the line, and because wire-line wickers cut cups and valves. These disadvantages are difficult to overcome, but once they are surmounted, the wire-line pump will be superior to the present pumping equipment.

Flow lines are all equipped with heaters made by welding two or more joints of larger pipe on the flow line and providing for an inlet and an outlet for steam. Some flow lines are equipped with steam jets welded into the flow line near the well. The periodic injection of steam cleans the paraffin out of the flow line.

Flow tanks, separators and stock tanks are all equipped with steam coils. The oil is kept above the congealing point and the paraffin remains in solution.

Experimental Heating of Panhandle Crude

Samples of Panhandle crude were heated for varying periods of time in closed vessels in a temperature-regulated electric oven. After a definite period of time, as indicated in Tables 3 to 6, a vessel was removed from the oven. A sample was taken and the vessel of heated crude stored at another temperature. A cold test was then taken on this first sample, which represented the state of the crude immediately after heating. At the stated periods of time, thereafter, another sample was removed and the cold test taken. A few viscosities were also taken and measured on two of the heated samples. These viscosities were taken at 100° F. and any effect on viscosity was probably lost through heating to this higher temperature. A sufficient amount of crude was heated to provide a number of samples for the measurements taken, without mixing these samples after testing with the original batch. The results obtained are summarized in Tables 3 to 6.

TABLE 3.—*Cold-test Hysteresis of Panhandle Crude*

Eight-well Composite, 36.6° A. P. I.

Heated Temperature, Deg. F.	Original Cold Test, Deg. F.	Storage Temperature, Deg. F.	Cold Tests (Deg. F.) Found after Storing for Time Indicated				
			0 Hr.	24 Hr.	48 Hr.	72 Hr.	96 Hr.
150	60	150	0	0	0	0	2
150	60	82	0	0	44	62	66
150	60	40	0	20	24	42	50
82	60	82	60	66	65	66	66
82	60	40	60	60	64	64	64

TABLE 4.—*Cold-test Hysteresis of Panhandle Crude*

Eight-well Composite, 36.6° A. P. I., Original Cold Test of 60° F.

Oven Temperature, Deg. F.	Time in Oven, Hr.	Storage Temperature, Deg. F.	Cold Tests (Deg. F.) Found after Storing for Time Indicated			
			0 Hr.	24 Hr.	48 Hr.	72 Hr.
115	2	40	0	23	16	34
115	4	40	0	0	16	18
115	12	40	2	18	22	36
115	24	40	0	28	38	48

TABLE 5.—*Cold-test Hysteresis of Panhandle Crude*

Eight-well Composite, 36.6° A. P. I., Original Cold Test of 60° F.

Oven Temperature, Deg. F.	Time in Oven, Hr.	Storage Temperature, Deg. F.	Cold Tests (Deg. F.) Found after Storing for Time Indicated			
			0 Hr.	24 Hr.	48 Hr.	72 Hr.
115	3	40	0	24	31	36
115	6	40	5	38	40	44
115	12	40	0	36	46	48
115	24	40	0	34	35	37

TABLE 6.—*Viscosity Hysteresis of Panhandle Crude*

Eight-well Composite, 36.6° A. P. I., 170 Sec. Saybolt at 100° F.

Oven Temperature, Deg. F.	Storage Temperature, Deg. F.	Average Saybolt Viscosities at 100° F. Found after Storing for Time Indicated			
		0 Hr.	24 Hr.	48 Hr.	72 Hr.
115	40	145	119	133	137
115	40	123	115	118	125

A sample of crude was heated in contact with fuller's earth, and another in contact with freshly burned lime. The crudes were then filtered and cold tests were taken as before. These results are summarized in Table 7.

TABLE 7.—*Cold-test Hysteresis of Panhandle Crude after Heating with Fuller's Earth and with Lime*

Burnett Crude, Original Cold Test 70° F.

Temperature Heated, Deg. F.	Heated with	Cold Tests after Storing at 85° F. for Time Indicated		
		48 Hr.	60 Hr.	84 Hr.
150	Fuller's earth..................	34	55	66
150	Fresh lime....................	20	50	67

Various producers in the Panhandle field were approached by salesmen selling compounds which it was claimed would reduce the cold test of the crude. Two samples of one of these compounds were obtained and were analyzed. The analysis of sample No. 1 was: NaOH, 21.8 per cent.; Na_2CO_3, 5.3 per cent.; crude naphthalene, 72.9 per cent. Sample No. 2 analyzed: Na_2CO_3, 25.0 per cent.; $NaHCO_3$, 2 per cent.; crude naphthalene, 73.0 per cent. The chemical originally was probably a mixture of sodium hydroxide and naphthalene, and absorbed carbon dioxide from the air. Cold-test experiments were performed with samples Nos. 1 and 2, which are summarized in Table 8.

TABLE 8.—*Cold-test Hysteresis of Panhandle Crude with Added Chemical*

Burnett Crude, Original Cold Test of 70° F., Stored at Room Temperature (85° F.)

Temperature Heated, Deg. F.	Chemical, Lb. per Bbl.	Cold Tests Found after Storing for Time Indicated			
		0 Hr.	12 Hr.	24 Hr.	48 Hr.
Series with Sample No. 1					
110	0—check	0	28	25	57
110	1.6	0	15	17	58
110	5.9	0	28	35	54
110	9.7	0	50	45	58
Series with Sample No. 2					
110	0—check	0	28	25	57
110	2.3	0	36	39	54
110	5.05	0	48	40	57
110	7.3	0	44	45	56

Discussion of Results

The data presented in Tables 3 to 8 are plotted in Figs. 1 to 7, respectively.

The results tabulated in Table 3 and plotted in Fig. 1 clearly demonstrate the effect of heating Panhandle crude. The original crude showed

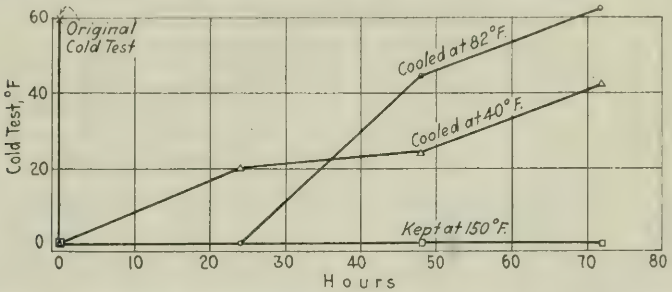


Fig. 1.—Cold-test hysteresis of Panhandle crude heated to 150° F.

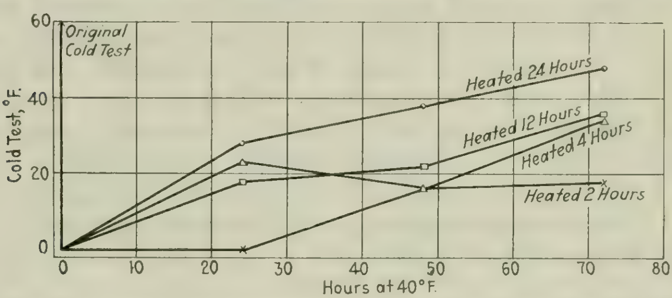


Fig. 2.—Cold-test hysteresis of Panhandle crude heated to 115° F.

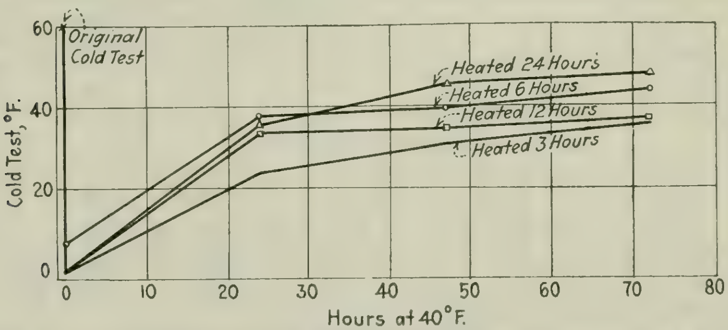


Fig. 3.—Cold-test hysteresis of Panhandle crude heated to 115° F.

a cold test of 60° F. The average room temperature during these experiments was 82° F. Four bottles filled with the crude were treated as indicated in Table 3 and Fig. 1. The bottles containing crude at 82° F. showed little change on standing at 82° F. and at 40° F. Heating to 150°

F. demonstrates the fact that the cold test of hot crude is kept at $\pm 0°$ F. This lowered cold test gradually regains its original value when kept at the lower temperatures of 40° and 82° F.

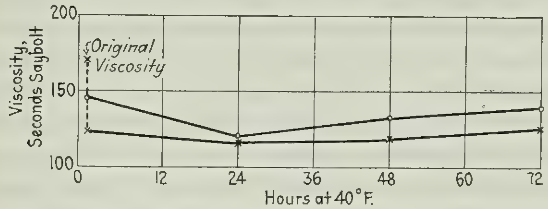


Fig. 4.—Viscosity hysteresis of Panhandle crude heated to 115° F.

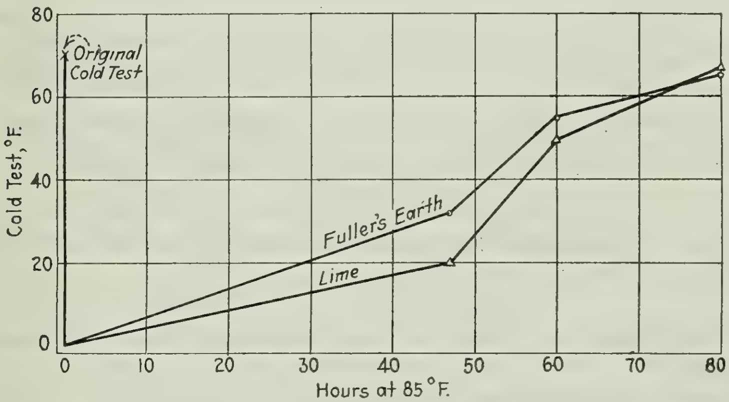


Fig. 5.—Cold-test hysteresis of Panhandle crude treated with fuller's earth and lime.

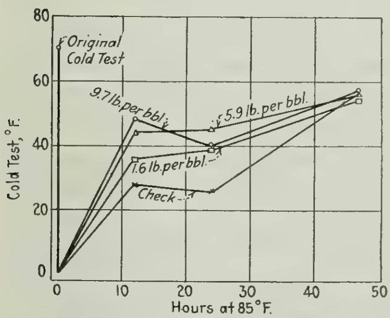


Fig. 6.—Cold-test hysteresis of Panhandle crude; chemical added, heated to 110° F.

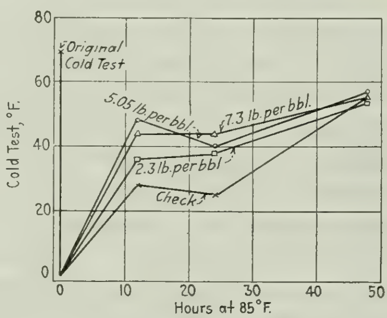


Fig. 7.—Cold-test hysteresis of Panhandle crude; chemical added; heated to 110° F.

The results tabulated in Tables 4 to 8 show the same hysteresis of Panhandle crude upon heating to 110° and 115° F. There is also an effect due to the temperature at which the heated samples were stored and the length of time the samples were allowed to remain in the oven. The

higher storage temperatures and the longer times of heating result in more rapid return of the oil to its original cold test. The cause is probably the same in each case. Any action, whether chemical or physical, proceeds at a faster rate as the temperature rises. Storing at a higher temperature restores the crude more quickly to its original condition. The effect of time of heating is undoubtedly due to the higher temperature attained by the crude on standing in the oven a longer period, and is due to the fact it was not heated to the higher temperature quickly. This increased heat content requires a longer period of time to dissipate, and, in effect, the temperature is maintained at a higher value during the initial period of cooling.

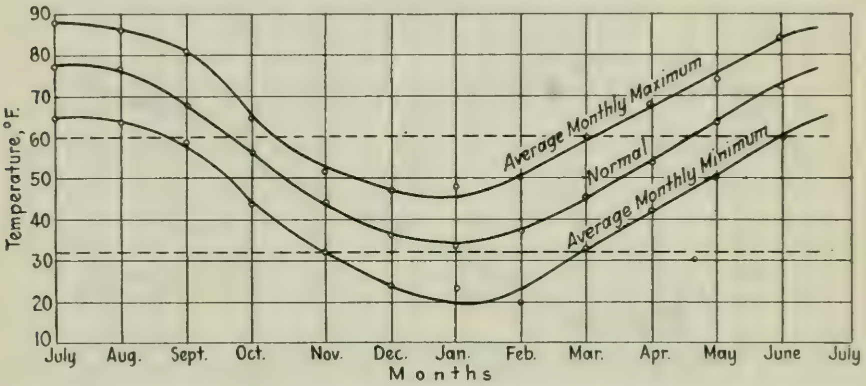


FIG. 8.—AVERAGE MONTHLY AIR TEMPERATURE FOR 28-YEAR PERIOD AT AMARILLO, TEXAS. DATA FURNISHED BY U. S. WEATHER BUREAU.

The effect of the added chemical is shown in Figs. 6 and 7 to be an acceleration of the return of the crude so treated to its original cold test.

This study of the cold test and viscosity characteristics was undertaken in the hope that it would yield information that would indicate the most satisfactory method of handling Panhandle crude during the winter months. Fig. 8 shows what temperatures may be expected in the Texas Panhandle during the year. The normal temperature drops below 60° F. during September, reaches a minimum of 34° in January, and does not rise above 60° until April. Soil temperatures 3 ft. below the surface may be taken as the normal air temperature. Operations must be carried on for six months during which the air temperature is below the cold-test temperature of the crude.

PIPE-LINE OPERATION

The low air and soil temperatures during the winter months forced the Panhandle operators to heat their oil in flow and stock tanks to keep it from congealing and to facilitate treating. The results of the experiments on Panhandle crude prove definitely that after the crude is heated to 115°

F. the cold test regains its original value slowly. Immediately after heating, the cold test is 0° F. or below, and a period of 12 to 30 hr. elapses before the cold test comes back to 32° F. This is illustrated in Figs. 1 to 7.

Winter movement of Panhandle crude through lease and various pipe lines had to be carried on with heated oil. All lines were buried 30 to 36 in. below the surface to reduce loss of heat. The loss of heat units from a heated oil line buried in the soil is that heat lost by conduction to the surrounding soil. The loss of heat is controlled, therefore, by the heat conductivity of the soil. Some typical conductivities are as follows:

Heat Loss to	K
Dry sand	0.2
Dry soil (summer)	0.4
Damp soil (winter)	0.75
Wet sand	2.00
Sand and moving water	2.00 plus
Air	2.00 plus

K = B. t. u. lost per square foot exposed surface per hour per degree Fahrenheit difference in temperature per foot thickness.

These data indicate the value of laying lines in a location with good drainage and protected from air and water currents.

Another important characteristic of Panhandle crude is the large viscosity-temperature effect, illustrated in Fig. 9. Panhandle crude at 125° F. approaches high-gravity Mid-Continent crude in its viscosity; at 50° F. the viscosity is comparable to a low-gravity asphalt-base oil. Comparisons are made by the plotting of these typical curves in Fig. 9. This thermoviscosity effect is an added reason for heating the oil for transportation, as capacities of the lines are greatly increased. Operation of pipe lines at maximum capacity reduces the time the oil is in the line and reduces the amount of heat lost per barrel of oil moved. Advantage may be taken of this by having the average and final line temperature, for the same initial temperature, much higher, or by reducing the intake temperature and B. t. u. per bbl. necessary to insure the same average and line temperature necessary as when pumping a smaller amount of oil.

Table 9 summarizes a few sample calculations as to what may be expected for an 8-in. line buried 36 in. under adverse conditions, since K is taken as 1 and the soil temperature 32° F. Some actual temperatures taken on an 8-in. heated oil line are given in Table 10.

The normal soil temperature at the time these tests were performed was between 45° and 55° F. The oil entered the pipe line at 120° F. and left the pipe line 11 miles away at 92° F. The pipe line was handling approximately 24,000 bbl. daily at the time, with a loss of 28° F., or

2.55° F. per mile. This corresponds to an average earth conductivity of $K = 0.68$.

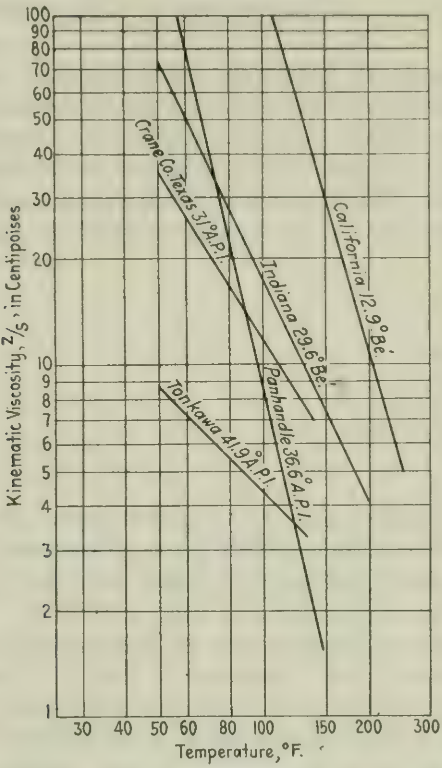


Fig. 9.—Temperature-viscosity characteristics of Panhandle and several other typical crudes.

Table 9.—*Temperature Drop in an 8-in. Heated Oil Line.*
$K = 1$. Soil Temperature = 32° F. Initial Oil Temperature = 115° F.

Rate of Flow, Bbl. per Day	Distance, Miles	Final Oil Temperature, Deg. F.	Time of Flow, Hr.	Probable Cold Test, Deg. F.
10,000	15	37	11.7	Below 32
	11	42	8.6	Below 25
	7.5	56	5.98	Below 20
20,000	15	51.5	5.9	Below 20
	11	60.5	4.3	Below 10
	7.5	74.5	2.99	Below 5
30,000	15	61.8	3.92	Below 15
	11	66.6	2.87	Below 5
	7.5	85.2	1.96	Below 0

The presence of small amounts of silt and the ever-present danger of paraffin forming in the pipe at points of sudden cooling (caused by water

currents, etc.) necessitates the frequent use of line scrapers or go-devils. Scrapers may be sent through the modern welded lines with little danger of hanging up in the line. The accepted practice in the Panhandle is to send a scraper through the line daily, or every other day.

As a result of exhaustive studies of the characteristics of Panhandle crude, the following practices have been put into force:

The pipe-line companies require that the oil be delivered to them on the lease at 90° F. This insures a good quality pumping fluid and a sufficiently high temperature to insure delivery to the station or tank farm.

TABLE 10.—*Field Data on 8-in. Buried Hot-oil Line*

Taken Nov. 30, 1926. Normal Temperature, 50° F.; Initial Oil Temperature, 120° F.

Time, P. M.	Air Temperature, Deg. F.	Distance from Heater	Soil Type	Depth of Reading, In.	Distance from Line, Ft.	Temperature of Soil, Deg. F.
12:00	73	11 miles	Tight black clay	30*	0	92
				34	1	79.7
				34	2	71.3
				34	20	53.5
	82	5.5 miles	Sandy soil	24*	0	92.2
				30	1	78
				30	2	71.5
				30	20	55.5
4:30	78	200 ft.	Sandy soil	32	0	101.5
				36	1	78.5
				36	2	69.7
				36	20	56.5

* On line.

Continuous operation is desirable in order to prevent the oil from congealing and the building up of high pressures when operation is again started. A shutdown of short duration can be tolerated because of the cold test lag, but a shutdown of 12 hr. or more may prove serious. Heat must be supplied continuously to the soil to maintain the temperature gradient. It takes more heat units to bring soil temperatures up to a steady state than to maintain them in that state. A shutdown of a heated line allows the soil heat to dissipate. The extra heat needed to restore the steady state must come from the fresh oil, which will be, in turn, cooled proportionately, and the friction and pressure increased.

Another interesting point brought out by these calculations, in order to determine the most favorable heating temperature and location of stations, was the saving in heat due to the lessened distance between stations. Table 11 shows the results that may be expected for the same conditions used in Table 8.

Table 11 shows that to maintain a temperature of 60° F. at the end of a pipe line, a spacing of stations 11 miles apart results in a fuel saving of 27 per cent. over a 15-mile spacing, and a spacing of 7.5 miles, or half the 15-mile spacing, results in a fuel saving of 51 per cent. Heating-station investment and operation costs would be increased 36 per cent. for the 11-mile plan and 100 per cent. for the 7.5-mile plan. A balance on fuel cost and flexibility would determine the most economic design for any one set of conditions.

TABLE 11.—*Reduction of Heating on Closer Spacing of Heating Stations*
20,000 Bbl. per Day. $K = 1$. Incoming Temperature = 70° F. Final Temperature Desired = 60° F. Average Panhandle Crude

Distance, Miles	Required Initial Temperature, Deg. F.	Millions of B. t. u. Required		Saving in B. t. u. Percentage over 15 Miles
		Each Station	15 Mile Equiv.	
15	144	232.	232.	0.
11	109	122.4	166.9	27.1
7.5	88	56.55	113.1	51.2

EFFECT OF PARAFFIN ON CORROSION

Panhandle crude contains an average of 0.8 per cent. sulfur. The gas in the granite wash area is sweet, while the gas in the lime area is sour, containing 0.4 to 0.8 per cent. hydrogen sulfide. The well brines are corrosive and the mixture of hydrogen sulfide and water constitute a highly corrosive mixture. There are a few gas-lift plants in the Panhandle obtaining their dry gas from the gasoline plants. This treated gas contains 1 to 10 per cent. air and the use of this gas to flow wells adds oxygen to the corrosive elements existing in the wells. Notwithstanding the corrosive well waters, the sulfur gas and the oxygen, very little corrosion of well tubing occurs. It has been noticed that corrosion in the Panhandle is limited to metal surfaces free of paraffin. It has previously been noted in this article that in most gas-lift wells paraffin forms from the bottom to the top of the tubing. Corrosion should be the greatest in gas-lift wells, but is found to be very small in extent. The paraffin forms a protective coating and considerably reduces the corrosion to be expected.

DISCUSSION

T. T. READ,* New York, N. Y.—I would like to ask Mr. Reistle a question about the general theory of solutions. If a heated solution is cooled you often find a decided lag in the crystallizing out of the solid; in heating a solution in contact with a solid there is also a lag in its going into solution. Do you find a lag in paraffin crystallizing out of its solution in petroleum, also in its going into solution in petroleum?

* Assistant Secretary, A. I. M. E.

C. E. Reistle, Jr.,* Laramie, Wyo.—There is a great deal of lag. Paraffin does not and will not settle out in many cases right away, nor will it go back into solution immediately when heated or agitated. We usually consider 24 hr. agitation sufficient.

W. V. Vietti.—I would like to ask Mr. Reistle a question in regard to my own work. I found that the samples that remained in the oven longest came back the more rapidly to the original cold test. You will notice in Fig. 1 that oil kept at 82° came back to the original cold test faster than when kept at 40°. I assumed that the samples that were in the oven only 3 hr. did not get heated through thoroughly. When I kept these samples at 40° they remained that way longer. This is entirely in the line of previous discussion on this point—it showed that the oil heated the hottest came back the fastest.

C. E. Reistle, Jr.—There seems to be a very interesting condition. We know we can get solution of wax in oil, as well as oil in wax. That question is in some way tied up with this—either we get wax melted and then dissolved in oil or vice versa. I hesitate to make a statement as to this. I do not know.

W. V. Vietti.—There should not be a difference between solid and liquid in the solvent once they are in solution in the liquid form.

C. E. Reistle, Jr.—That seems to be the condition. There is a point there I do not know about. Wax dissolves in gasoline and gasoline dissolves in wax.

R. Van A. Mills,† Bartlesville, Okla.—Assuming that Dr. Vietti's statement that increasing the gas pressure should decrease the solubility of paraffin is correct—accepting that relationship as our working hypothesis—I would then like to ask Dr. Vietti:

1. Why in Mr. Wood's experiments did the paraffin in solution in oil fail to precipitate out of the oil at relatively high gas pressure, when at the same temperature it would precipitate out readily at lower pressure? Does this not indicate an increase in the solubility of paraffin in oil with the increase of gas pressure?

2. Why, in our work in the Salt Creek field, were we able to remove paraffin from a 2-in. tubing in the well, and then keep the tubing relatively free of paraffin by stopcocking, if the paraffin was less soluble in the oil at the increased pressures? By letting the well stand for 24 hr. at approximately 400 lb. pressure—I do not remember the exact pressure—the paraffin flowed out of the well when it was subsequently opened for 24 hr. It looks as if that paraffin had been greatly softened and as if some of it may have gone into solution in the oil. It would be most interesting to have this explained. Is there a possibility that the oil mixed with the paraffin absorbs gas enough to lower the viscosity of the mixture of paraffin and oil so that the paraffin is easily blown out? Is it not also reasonable to expect more of the paraffin to go into solution in the oil under these conditions?

W. V. Vietti.—To Mr. Mills' first question, I was speaking only about the effect of pressure on the solubility of paraffin. Gas will dissolve in paraffin as it will in any other like material. As to blowing paraffin out of the well: If you hold pressure against it, gas will dissolve in the wax. Sudden release of pressure would have much greater effect on shoving the plug of paraffin out at 450 lb. than 900 lb. gradually applied.

T. T. Read.—It is undoubtedly true that if you put pressure on the petroleum you will decrease the solubility of the paraffin in the petroleum, but if you put pressure

---

* U. S. Bureau of Mines.

† Petroleum Engineer, U. S. Bureau of Mines.

on a gas-oil mixture you will increase the amount of gas in solution in the petroleum. I have no data to substantiate it, but it seems to me that paraffin might be very much more soluble in a gas-oil mixture than in oil alone. If that is true, the situation would exist under pressure that the solubility of paraffin in oil would slightly decrease and its solubility in the gas-oil solution greatly increase, with a net positive increase in the solubility. In other words, where you have two factors working against each other and the plus effect is greater than the minus effect, you would get a net plus. This would explain an apparent decrease in the solubility of paraffin when the pressure is released; it would result from the escape of the gas that had helped hold it in the solution.

Chapter V. Increasing the Extraction of Oil

Effect of Repressuring Producing Sands during the Flush Stage of Production

By E. V. Foran,* Fort Worth, Texas

(New York Meeting, February, 1928)

The repressuring of oil-producing formations during the flush stage of production, although requiring primarily the same procedure as operations on formations where the gas pressure has been depleted, offers several advantages of major importance, the value of which has not heretofore been demonstrated. It is the purpose of this paper to present an account of some recent operations of this character and the economic effects on the properties where they were applied.

The principal objective in all repressuring operations is to secure an effective diffusion of the input energy to all parts of the producing sand. If this can be accomplished, success is assured during the remainder of the life of the property; if not, it will be temporary only and will be followed by difficulties, and the maximum possible recovery will not be obtained.

During the past year in Texas, the Cook pool in Shackelford County, and the Turbeville pool in Archer County, while still in their flush stage of production, have been subjected to repressuring operations to observe their reaction to this process during the early stage of their productive periods. The repressuring operations carried on in each of these pools will be discussed separately in this paper in order to show peculiarities which were present in one pool but were not observed in the other.

Turbeville Pool

The Turbeville pool is in Archer County, about 30 miles south of Wichita Falls. The productive sand varies in thickness from 10 to 30 ft., the average being about 16 ft. The depth of the sand varies from 1450 to 1530 ft. The developed productive area to date is approximately 200 acres, but the limits of the pool have not yet been proved. The sand varies considerably in different parts of the pool with respect to both porosity and permeability. The gravity of the oil varies from 39 to 41° A. P. I. There were some wells which flowed for a few days after completion but during 1927 all production was secured by pumping. The

* Production Engineer, Marland Oil Co. of Texas.

initial gas reserve was very small and its depletion was marked by a very rapid decline. There are six operators in the pool and, to simplify reference to the map, the leases will be designated by alphabetical letters.

Preliminary Survey of Turbeville Pool

During the latter part of May, 1927, the Marland Oil Co. made a preliminary survey of subsurface conditions to determine the natural distribution of the gas in different parts of lease *B* (see Fig. 1). The

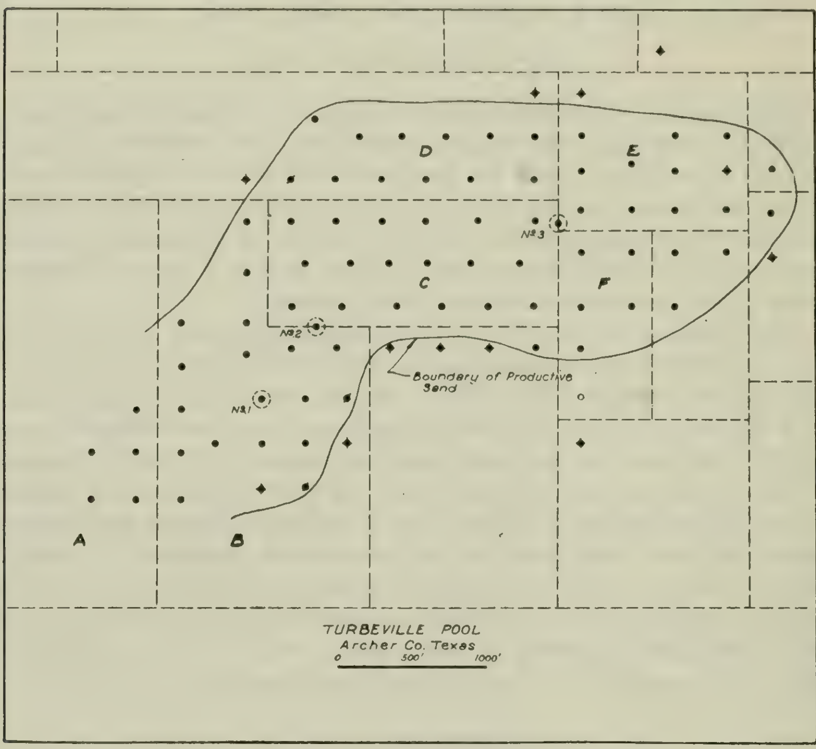


Fig. 1.—Preliminary survey of Turbeville pool.

results of this survey showed the gas-oil ratio to be fairly uniform throughout the lease, which was interpreted as favorable to repressuring operations. The natural ratio at that time was 270 cu. ft. per bbl. No rock pressures were determined during this survey but it was estimated that the original rock pressure was probably not over 225 lb. There were several wells on lease *B* which were completed in areas where the sand was very tight and these wells made small initial production which was followed by a very rapid decline. It was deemed advisable to use these tight-sand wells as input or key wells wherever possible and to drive the

oil from the tight-sand areas to the loose-sand areas where recovery was certain to be made. This led to the selection of a tight-sand input well which was centrally located in lease *B*. Although there was a surplus of gas available at the time, it was decided to introduce air into the input well during the first 30 days and analyze the output gas from the surrounding wells to determine the path of the input air and its degree of diffusion and range of influence in the different directions in which it traveled.

Equipment Used at Turbeville

This was equipped with a two-stage portable compressor of 150,000 cu. ft. daily capacity, which remained in service until results indicated that success was assured. The input air to the key well was measured daily through an orifice meter. This compressor was replaced, after 35 days operation, by an 80-hp. two-stage compressor, which was installed for permanent operation; at the same time, gas-gathering lines were laid to the casingheads of all the producing wells and meters installed at the compressor intake and output to record distribution and consumption of gas.

Operating Data, Turbeville Pool

Active operations were started on June 4, 1927, when 70,000 cu. ft. of air daily was forced into the sand through input well No. 1 (Fig. 1). The rock pressure on lease *B* at this time, based on fluid-level observations, was approximately 90 lb. and the pressure required for the sand to absorb 70,000 cu. ft. of air daily was 185 lb. As this was the first attempt at repressuring in this pool, and it was still in the flush stage of production, it was impossible to forecast any probable results. Recording measurements were made daily on the volume of gas from each of the first and second-line wells surrounding the input well. Daily oil gages were also obtained from each of the wells from which gas was being measured.

Just prior to the introduction of the air, lease *B* was producing 450 bbl. oil and 128,000 cu. ft. of gas daily. This showed a gas-oil ratio of 285 cu. ft. per barrel.

Results of Air Drive at Turbeville

During the first 10 days following the injection of the air, some slight increases in oil and gas were observed but were not regarded as being of any importance. The output gas from all wells was analyzed daily for any traces of air that might be detected but none was observed, although more than 700,000 cu. ft. had entered the sand during this 10-day period. However, the second 10-day period following the injection of air showed some marked increases in both oil and gas production. These increases extended in two directions, one location to the east, and two locations to

the west of the input well. A careful analysis for air showed no traces present. No changes were made with respect to the volume of input air which was entering the sand, as the increased production on each side of the input well indicated, that a satisfactory distribution was being obtained.

At the end of the first 30-day period of operations, the range of pressure influence had extended beyond the boundaries of lease *B* both to the east and west of the input well. The influence to the west seemed much more marked than to the east. The persistent increases in oil and gas production in this direction were interpreted as indicating a rapid migration of the air westward. As a desirable counter force to act against the migration of too much air in this direction, the tubing of the wells that showed the greatest increases was raised from 20 to 40 ft. above the customary level, which was the top of the sand. This resulted in a sudden drop in production in these wells due to the low rock pressure, therefore this practice was abandoned and, instead, the volume of input air was reduced to a point which was insufficient to extent its influence beyond the borders of the lease.

Recirculation of Wet Gas

On July 9, the portable air compressor was shut down and the casinghead gas was delivered to an 80-hp. two-stage compressor, which returned 50,000 cu. ft. of wet gas to the input well. No attempt was made to extract any gasoline from the gas, as this would require condensing coils and absorbers; also, it was considered an advantage to return wet gas to the sand, as this would retard the natural téndency of the remaining oil in the sand to become increasingly viscous from its otherwise constant contact with circulating dry gas or air. The recirculated wet gas showed 2.1 gal. of gasoline per 1000 cu. ft.

During the period June 4 to July 9 inclusive, there was a total of 2,404,000 cu. ft. of air injected into the sand through the No. 1 input well, but no trace of it was found during this period. During the latter part of July, the tubing levels were raised again in an attempt to allow the return of greater volumes of gas to the sand without the dangers of "by-passing" or "channelling." This result was not successful because the rock pressure was too low to even produce oil against a fluid head of only 20 or 30 feet.

Velocity and Diffusion of Air and Gas in Sand

On July 29 (55 days after the start of operations), air was detected in the casinghead gas from the well one location (300 ft.) to the east of the input well. This was followed by the appearance of air in two more wells to the northeast of the input well, one on July 31 and the other on

Aug. 2. The air content of the gas from these wells varied from 6 to 12 per cent. during the first three days and reached its peak about 10

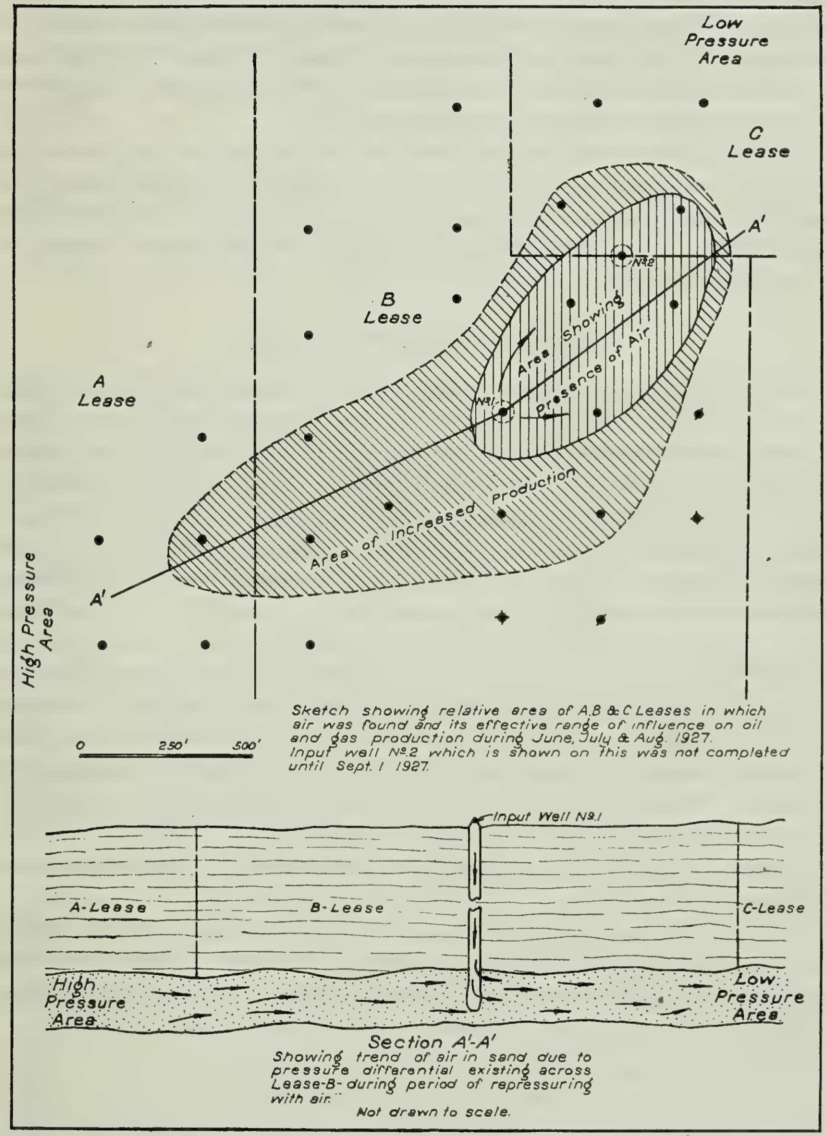


FIG. 2.—AREAS OF AIR CONTENT, TURBEVILLE POOL.

days later, showing 23 per cent. on one well, 16 per cent. on another and 9 per cent. on the third well.

The path of the air (see Fig. 2) was fan-shaped, radiating from the input well in a general northeastward direction. The average velocity

of the air in its course to the nearest well was approximately 6 ft. per day. Undoubtedly the velocity of the air close to the input well was much greater than this, but due to progressive diffusion and radiation, its velocity became very slow before appearing in the offset wells. The air content in the three wells mentioned remained from 4 to 9 per cent. for 40 days following its first appearance. This is further indication of complete diffusion of the air in the formation.

Although the casinghead gas from each of the wells to the west of the input well was carefully analyzed for air during the period June 10 to Dec. 31, no trace was found in any of them. In spite of this fact, these wells showed the greatest increase of gas and oil production during the period of repressuring.

Natural Migration of Gas and Oil

After mapping the course of the air in the sand (Fig. 2) and noting its effects, it at once became apparent that the increased production to the west of the input well was the result of blockading an active stream of oil and gas whose origin was somewhere in lease *A*, which is known to be the area of highest pressure in the pool, to areas of lower pressure which are known to exist to the east of lease *B*. The rock pressure during this period at input well No. 1 was known to be 70 lb. while the pressure at input well No. 2 (completed Sept. 1) was 30 lb. From these data it was assumed that the rock pressure on lease *A* was probably 90 or 100 lb. per sq. in. This would indicate that a pressure differential of 60 or 70 lb. per sq. in. was sufficient to cause an appreciable drainage of oil from lease *A* to areas of lower pressure, although there were first and second-line wells completed on this lease for protection against such drainage. The wells on lease *A* were the last in this pool to be completed before the suspension of development operations in April, 1927. The productive limits of the pool had been reached in all directions except to the west of lease *A*.

Had gas been used as an input medium during the first 35 days, instead of air, the increased gas and oil production to the west of the input well would have been interpreted as evidence of the input gas going in that direction, whereas the exact opposite was proved to have occurred.

Volume of Circulating Gas

On Sept. 1, a "five-spot" input well, to be owned and operated jointly by the Texas Co. and the Marland Oil Co., was completed on the boundary line of the *B* and *C* leases. The Texas Co., operators of lease *C*, completed a repressure plant on Sept. 5 and in October completed a second "five-spot" input well on the east border of lease *C*. Air was injected into input well No. 2 on the *B* and *C* lease boundary line for a

period of seven days, after which it was replaced by wet gas. The air was observed to move rapidly eastward through the sand, which was expected since the lowest pressure area was known to be in this direction.

Table 1 shows the average daily volumes of input and output gas on leases *B* and *C*, together with the production data for their respective periods of observation before and during repressure operations, to Jan. 1, 1928.

TABLE 1.—*Data on Leases B and C before and during Repressuring*

Month	Input Gas, Cu. Ft.	Output Gas, Cu. Ft.	Net Gas from Sand, Cu. Ft.	Oil, Bbl.	Net Formation Ft./Bbl. Ratio	Remarks
			Lease *B*—May 1 to Dec. 31, 1927			
May........	None	145,000	145,000	540	268	Normal operations
June........	74,000	123,000	49,000	454	108	Repressuring with air
July........	42,000	95,000	53,000	440	120	Repressuring with wet gas
Aug........	38,000	80,000	42,000	415	101	Repressuring with wet gas
Sept........	91,000	76,000	None	337	0	Attempt to restore pressure
Oct.........	86,000	88,000	2,000	299	7	Raised tubing levels
Nov........	47,000	100,000	53,000	306	173	Lowered tubing to normal
Dec........	59,000	106,000	47,000	290	162	Normal repressuring
			Lease *C*—Aug. 1 to Dec. 31, 1927			
Aug........	None	90,000	90,000	575	172	Normal operations
Sept........	45,000	85,000	40,000	555	72	Repressuring wet gas
Oct.........	83,000	110,000	27,000	639	42	Repressuring wet gas
Nov........	82,000	105,000	23,000	577	40	Repressuring wet gas
Dec........	65,000	90,000	25,000	540	46	Repressuring wet gas

In studying the table, it will be noted that during the months of September and October there was no loss of gas from the subsurface reserve, as increased quantities of air were forced into the sand in order to increase pressure in the sand while extracting normal production from it at the same time. There was no by-passing due to high fluid levels maintained on the *B* lease. The only reaction was a sharp increase in production on the *C* lease, as this was a lower pressure area than the *B* lease. Although the line wells on the *C* lease were subjected to high back-pressures they did not form an effective barrier against the large volumes of input gas and air forced in the "five-spot" well on the *B* and *C* lease boundary line.

This table shows how the repressuring of flush pools offers a possible solution for the conservation question, which, although widely discussed, has remained unsolved to date.

Utilization of Wet Gas

All repressure operations on both the *B* and *C* leases are being carried on with wet gas and no attempt is being made to condense any of the vapors from the compressor output gas. The stock tanks on lease *B* are kept at a pressure of ½ oz. below atmosphere by means of a sensitive vacuum regulator which delivers the vapors to the compressor for return to the sand. Under these conditions, there is absolutely no vapor loss either in winter or summer, whether the tanks are vapor-tight or not. If the tanks are not vapor-tight, a small amount of air may enter the lines but no gasoline vapors can be lost to the air. It has also been observed that the recirculation of wet gas is the only method by which the oil reaches the tanks at the maximum possible gravity. Also, when repressuring any producing formation at relatively low pressures, as is the case in the Turbeville pool, it becomes a valuable asset to return the gas as wet as possible, as the oil is capable of absorbing and retaining in solution considerable quantities of wet gas even under pressures of only 70 or 80 lb., whereas residue gas or air would remain largely in the free or possibly occluded state in its relation to the oil.

Effect on Water Encroachment

An increase in bottom water was observed following the rapid decline in production on both the *B* and *C* leases. Soon after the beginning of repressure operations on the *B* lease, the water disappeared entirely in some of the wells and in the other cases further encroachment was entirely arrested. During the period from June, 1927, to January, 1928, there was no increase in water production from this lease. The *C* lease shows a similar history with respect to water.

Ultimate Production, Turbeville Pool

The relative increases in daily production observed from repressuring during the flush stage are not as pronounced as those generally observed where these operations are delayed until the point of economic exhaustion is reached by normal methods. However, the actual net gain in barrels per day and ultimate are greater and the time factor required to produce oil is reduced.

Table 2 shows relative production data and the rise in indicated ultimate production from the two leases caused by the repressuring process. Fig. 3 shows graphically the effect on the production decline of these leases due to these operations. The higher investment figure noted on the *B* lease was due to the use of oversize compressor equipment as this was available and was transferred from another lease to avoid the necessity of purchasing new and lower cost equipment more suitable in size for the operations on this lease. All of the equipment on the *C* lease was new.

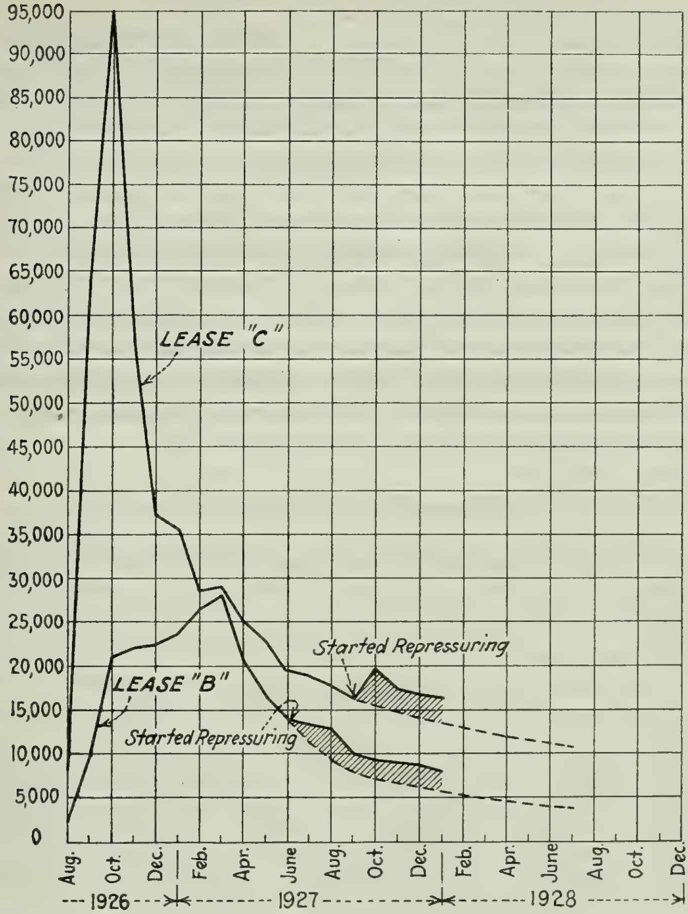


FIG. 3.—PRODUCTION CURVES, TURBEVILLE POOL.

TABLE 2.—*Data Showing Effect of Repressuring*

	Lease *B*	Lease *C*
Number producing wells	15	18
Number acres productive sand	44	38
Monthly peak production	28,096	94,848
Total production prior to repressuring, barrels	192,300	459,030
Normal indicated ultimate production, barrels	290,000	
Indicated ultimate by repressure process, barrels	380,000	
Net ultimate increase, barrels	90,000	
Per acre yield to Jan. 1, 1928, barrels	6,130	14,300
Per acre yield ultimate, barrels	8,650	
Investment in repressure equipment	$ 12,000	$ 8,000

Analysis of the data on Fig. 3 shows that the *B* lease repressure investment was returned during the first five months of operations and *C* lease investment was returned in less than four months of operations. This was accomplished with the price of 40 gravity oil at $1.36 per barrel.

Cook Pool

The Cook pool is located in Shackelford County, Texas, about 6 miles north of Albany. The producing sand in this pool is classified as a member of the Cisco series and is found at a depth of from 1100 to 1350 ft. The sand varies in thickness from 6 to 30 ft., averaging about 20 ft. The structure is well defined, showing a known area of dry gas sand of about 15 acres which occupies the high portion area of the main producing sand. The known productive area of the principal sand was approximately 1000 acres on Jan. 1, 1928. The well spacing is 300 feet.

Development Prior to Repressuring

The first production from the pool was obtained in March, 1926, and the development was very rapid until March, 1927. During this period, more than 200 producing wells were completed in the pool, leaving a large favorably located area still undeveloped. A few of the wells flowed for a period of 60 to 90 days following completion, but on account of the lack of high initial rock pressure, 90 per cent. of the completions were pumpers. The initial daily production of the wells varied from 30 to 1500 bbl., averaging about 125 bbl. The gravity of the oil varies from 37° to 41° A. P. I. There are six companies operating in the pool but Roeser & Pendleton, Inc., Roeser & Pendleton & Marland, and the Humble Oil & Refining Co. are the only operators who are repressuring their properties.

Preliminary Survey of Cook Pool

During April, 1927, a preliminary survey was conducted by Roeser & Pendleton & Marland for the purpose of indicating the possible advantages of repressuring the pool while still in the flush stage. The gas-oil ratio was observed to vary from 350 to 1300 cu. ft. per bbl., averaging about 900 cu. ft. Average daily production at this time was 7700 barrels.

A representative area in the south part of the pool was chosen for a repressure test and operations were started Apr. 9, 1927. The area in which the tests were carried on showed a rock pressure of from 90 to 110 lb. per sq. in., these pressures being determined by pressure gages submerged to the bottom of the full static column of oil. Although an abundance of gas was available at the start of operations, air was injected in the sand for 10 days through a well which had been a regular producer but which was temporarily killed in order to serve as an input well. The

input well was surrounded by eight producing wells, four being direct offsets and four, diagonal offsets.

A two-stage portable compressor served to inject the air into the sand. The input pressure required was 165 lb. The meters showed that a total of 770,000 cu. ft. of air had entered the sand during the first 10 days. The air was then discontinued and residue gas was returned to the sand during the remainder of the test period.

Results of Preliminary Tests

Increases in production of the surrounding wells were observed on the sixth day following the start of operations. The casinghead gas from the surrounding wells was analyzed for air during the next 40 days. The air appeared in six of the wells in a highly diffused state, which was indicated by the fact that the air content of the gas did not exceed 4 per cent. at any time during the 21 days that it was present as a component of the output gas. The air made its first appearance 14 days following the start of operations and disappeared 35 days after the start. There was no evidence of "channelling" and the ratio did not change from that of the normal pre-testing period. The input air and gas entered the sand during the period Apr. 7 to May 5, 1927.

Permanent Equipment for Cook Pool

Following the preliminary work, a permanent plant was installed in July, which is capable of handling 4,500,000 cu. ft. at the required pressures to return the residue gas from a casinghead gasoline plant to the sand. This plant started work on July 13, 1927, and has been in continuous operation since. The compressor equipment, together with field lines, meters, etc., represents an investment of $80,000. This equipment is the joint property of Roeser & Pendleton and the Marland Oil Co., whose properties produce nearly 95 per cent. of the production from this pool. This plant also delivers gas for repressure purposes to the Humble Oil & Refining Co's. 80-acre lease.

The compression plant during the prorate period handled an average of 1,050,000 cu. ft. per day and distributed it to the input wells through 14 volume-control orifice meters. The average daily wet gas production from the pool during the prorate period was 2,900,000 cubic feet.

Method of Operations at Cook Pool

Because the ownership status of the leases in this pool is similar to that where unit control prevails, the greater portion of the production has been shut in since May, 1927, the lease-line wells and those in the zone

of water encroachment being the only ones from which production has been extracted at normal capacity; the remaining wells being produced at not more than 30 per cent. of their normal capacity during this period. As the wells were on a prorate basis while being repressured, it is difficult at this time to forecast the effect of repressuring on the ultimate recovery from this pool, but the observations that have been made to date are indicative of a degree of success that promises to recognize repressure operations in flush pools as a forward step in production methods.

In January, 1928, during two periods of brief duration, there were two 80-acre leases subjected to unrestricted production tests. Both of them showed 25 per cent. increase over the rate of the last former unrestricted production, which was gaged before the proration plan was adopted. The duration of these tests was four days on one lease and seven days on the other. There was no evidence of gas "channelling" during this test. During the period July 13, 1927, to Jan. 15, 1928, there was a total of 185,000,000 cu. ft. of residue gas returned through the 14 input wells. This represented 38 per cent. of the total wet gas production for the same period. The pressure required to return this gas to the sand varied from 60 to 170 lb. The initial rock pressure of the Cook pool is not known, but was probably around 250 pounds.

Back-pressure Control

Several methods were tested out as a means of controlling the gas-oil ratio, which at times became so high that it threatened the success of the entire project.

Tubing levels were raised progressively to allow a fluid column to remain constantly against the sand and act as a back-pressure, but this was not satisfactory, for two reasons: (1) while this insured a column of oil against the sand, the variations in the weight of this column in small wells, due to pumping off, often unbalanced the pressure equilibrium at the bottom of the well and the gas would break through and become difficult to control; (2) it was not considered good practice to follow, in cases where bottom water was being produced with the oil, as the water would tend to concentrate in the lower part of the well and constantly cover the sand.

A liner with a packer which forced all gas and oil to first go downward to the bottom of the hole before its escape into the casing was also tried as a means to reduce the gas-oil ratio, but was unsatisfactory. Finally it was decided to leave the working barrel at the normal position above the top of the sand and adjust the length and speed of the stroke so that the producing formation would never be uncovered, but there would always be fluid at a sufficient elevation above the top of the sand to constantly maintain the desired pressure. The plunger displacement

was adjusted to the point that was observed to give the lowest gas-oil ratio consistent with the production obtained. This method had been tried previously as a remedy for troubles in the repressure work in the Turbeville pool, where it gave instant success, and it was equally successful at the Cook pool.

Red-line multiplier posts are being installed on all wells, which permits the adjustment of the plunger displacement to a very fine degree. Where the wells are small, a working barrel of small diameter is used. This method enables the operator to obtain a remarkable stability of pressure conditions in the sand and a positive control of the movements and distribution of the gas through the sand. After the proper speed and length of stroke for a well are determined, it requires little further attention.

Conclusions

The observations and results of the repressuring operations which have been in progress during the past eight months in the pools described in this paper, strongly support the following conclusions:

1. The repressuring of producing sands during the flush stage of production is the only method by which water encroachment can be retarded to any appreciable degree. Maintaining high back-pressures without repressuring may prevent local "coning" of bottom water but will not retard progressive encroachment.

2. The flush stage is generally the only time during the producing life of the pool when an adequate supply of cheap gas is available for return to the sand. Air, which is always available, cannot be used in some cases because of its corrosive action.

3. When repressuring permits the pumping of wells under moderate back-pressures, as in the case of the Cook pool, a large quantity of dissolved gas remains in solution in the oil until after it has reached the well. This results in a lower viscosity of the oil and therefore higher ultimate recoveries.

4. The use of wet gas is better than dry gas, especially when repressuring at low pressures, because it is more soluble in oil than dry gas under these conditions.

5. Fewer wells will be required to recover the oil from any unit area when that area is subjected to repressure operations during the flush stage.

6. It is proved beyond all doubt that conservation of gas energy in any producing sand increases the ultimate recovery from that sand.

7. The repressuring of producing sands during the flush stage of production offers a method by which true conservation may be applied on a dividend-paying basis.

DISCUSSION

J. F. Hanst,* Pittsburgh, Pa.—There is considerable food for thought in this paper. The process of repressuring oil sands, commonly known as the Smith-Dunn or Marietta process, was tried out in certain parts of West Virginia and Western Pennsylvania even before Smith and Dunn brought it into prominence, and met with varying success from the start. In Pennsylvania, it was condemned by many operators, principally because of lack of knowledge of how to apply pressure, and because results were expected too quickly. It was brought out just a little while ago that we cannot expect to put back in a few weeks what it has taken Nature a great many years to accomplish; nevertheless, many operators of today are attempting just that, and naturally are not meeting with the success they should obtain.

It has been my experience that wherever pressure is properly applied results have been highly gratifying. This is true of practically all producing sands, excepting those which are not sands at all, but limestones. In the lime "sands," the oil is apparently not uniformly distributed throughout the producing horizon, and occurs more or less in "pockets." Besides, the lime is apt to be full of cracks or fissures, which permit the pressure to be dissipated without doing useful work.

In the Titusville and Oil City fields of Pennsylvania, results have been almost uniformly successful in recent years, due to more intelligent application and more careful planning. It has been conclusively demonstrated that gradual application of pressure is more beneficial than application of high pressures immediately at the start of operations, and that the lowest pressure that will cause uniform pressure throughout the sand is the one that produces the best results. One prominent operator in West Virginia started off with about 400 lb. pressure; he got a wonderful increase for a few weeks, then production fell off until it was lower than before air was applied. After some weeks, it was decided to switch the air well to another location and apply the pressure gradually. Finally it was found that about 90 lb. gave a steady increase in production; later this was dropped to about 60 lb., where it has stayed ever since.

In the Tidioute and Tionesta fields in Northern Pennsylvania, one operator bought an apparently exhausted lease comprising 10 wells. At the time he took it over, the property was making on an average of 2 bbl. per *week* from 10 wells. Air was applied at 160 lb. pressure, with a small two-stage Ingersoll-Rand compressor, belt driven from a Franklin gas engine. At first the property did not produce sufficient gas even to run the engine, so a gasoline carburetor was installed. After a few weeks, gas was coming in such quantities that there was enough not only to run the engine but to furnish fuel and light for three houses, run the lease, and have a surplus. The gas was then put back into the sand instead of air, and in less than one year the production had increased from 3 bbl. per *week* to 22 bbl. per *day;* at one time, it made as high as 27 bbl. per day. To operators from the Southwest, these may seem trifling figures, but calculate the percentage of increase, and I will venture to say that it will be as good, if not better, than the average returns obtained in other fields.

J. B. Umpleby,† Oklahoma City, Okla.—Because this matter of maintaining energy in oil sands is being given such wide attention at present, I think Mr. Foran has made a real contribution in pointing out that it is worth while to first start in air and then follow it by gas. The air can be traced from well to well, thus giving an analysis of sand conditions, but the gas is probably the more effective expellant of oil because of its greater solubility in the oil.

---

* Acting Manager, Ingersoll-Rand Co.

† President, Goldelline Oil Corpn.

Summary of Repressuring Experiments in California Fields

By A. H. Bell,* Seal Beach, Calif.

(New York Meeting, February, 1928)

The results of repressuring (or gas-drive) have been very encouraging to the several companies doing experimental work along these lines in California. The most notable examples are the Shell and the Union Oil companies at Dominguez, the Marland Oil Co. at Seal Beach, and the California Petroleum Corpn. at South Mountain.

The results of the Marland test at Seal Beach are interesting in that repressuring was started while several wells were still flowing; also, on account of the high pressures required to overcome the hydrostatic pressure exerted by high-head edge water.

The well first chosen for repressuring is about halfway up the flank of the structure and had been on the beam making about 250 bbl. of fluid daily, cutting about 60 per cent. emulsion. The fluid level was 230 ft. from the surface and the top of the sand was 4393 ft. Tubing was run to 4000 ft. with a packer and the space above the packer was filled with water to balance the high pressures.

Gas was started in slowly to allow the fluid to be pushed back into the sand, and required three days at a pressure of 1500 lb. per sq. in. before starting into formation. The pressure was once built up to 1800 lb. and the compressor was shut down for a few hours. When again started, the well took gas at 1500 lb., and after about three weeks the pressure was dropped to 1450 lb. The present pressures required range between 1400 and 1450 lb. Volumes as high as 1,500,000 cu. ft. per 24 hr. were put into the well.

Increases as high as 50 per cent. in production were obtained in wells up-structure with very little increase in wells down-structure. Also, the water cut on one edge well materially decreased. After about 40 days the repressuring was moved to two wells farther down-structure and the well originally repressured was put on production. The result of this was a great increase in the production of wells one location farther down-structure, a rapid increase in one well one location up-structure, and a decrease in production of the wells farthest up-structure. Later the gas started to short-cut to the nearest well down-structure, nullifying to a certain extent the effects of the repressuring work. The increased production that could be definitely attributed to the repressuring work

* Chief Production Engineer, Marland Oil Co. of California.

amounted to 1 bbl. for each 495 cu. ft. of gas introduced, and the increased gas production amounted to about 80 per cent. of the gas introduced.

The interesting features of repressuring work as encountered in the various projects in California, and which appeared similar in all of the projects, are as follows:

1. A rapid increase in production occurs during the first few months of repressuring with a falling off to a point slightly above normal, after which usual declines continue at a fixed figure above normal production.

2. The usual tendency is for the gas to travel up-structure and show the greatest increase in up-structure wells. Selection of several edge wells for a concerted drive up-structure is more advantageous than so-called "five-spot locations."

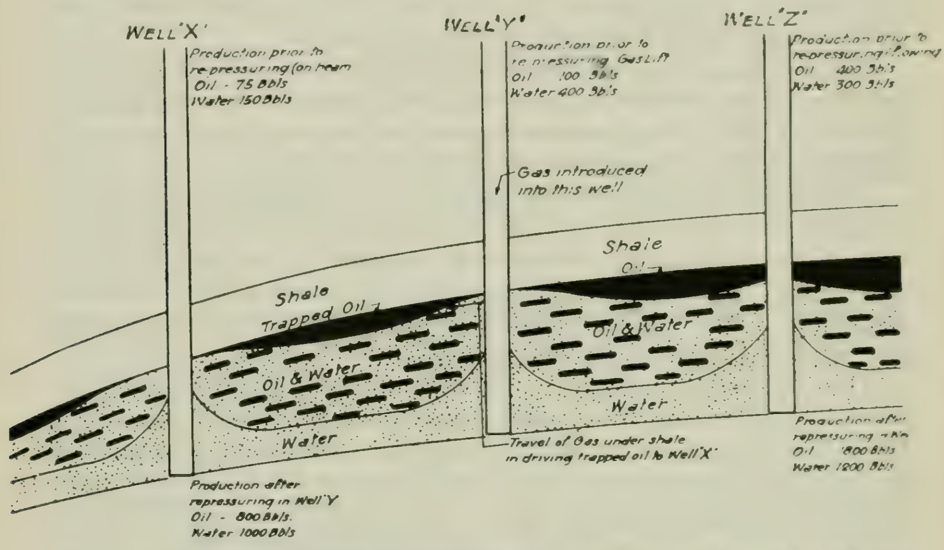


FIG. 1.—DIAGRAMMATIC SECTION THROUGH WELLS ON FLANK OF STRUCTURE AFFECTED BY REPRESSURING—SEAL BEACH FIELD.

Wells X and Y had both nearly reached points of commercial exhaustion by old methods. The large increase in production in well X without change in pumping equipment indicates recovery of oil that would have been left in sand without repressuring.

3. The greatest danger to successful results is from channelling of the gas to some near-by well, which increases rapidly after once starting.

4. In the average California field, the effects of repressuring will extend several locations, preventing its use on small properties except by cooperative efforts.

5. Pressures higher than formerly thought economical or safe can be used if equipment is properly designed.

6. Repressuring steadies the flow in gas-lift wells, greatly enhancing the value of gas-lift operations.

7. Fig. 1 shows graphically the oil recovered from a well in the Seal Beach field that would probably not have been recovered by other methods, indicating one source of greater ultimate recovery by repressuring. This condition existed at two different groups of wells.

8. In coarse-grained sands the effect of repressuring travels far enough to indicate the possibility of greater well spacing than would otherwise be considered necessary, using the gas-drive to drain the intervening areas. The reduced cost of such a program is self-evident.

DISCUSSION

C. E. Beecher,* Bartlesville, Okla.—The part of Mr. Bell's paper that deals with repressuring in the early life of a field, I consider most important. Of the various methods we now have available for obtaining a greater per cent. of oil from the sands, this one should give the best results. We are at present repressuring old fields to some extent in limited areas. If the same energy applied to an old field should be used on a new field, I believe the increased amount of oil recovered would be greatly in favor of early repressuring. In the early life of a field, before the pressure has been dissipated, the oil is well saturated with gas; as a result the viscosity and surface tension are both reduced and the oil moves through the sand more readily or with less resistance. Also, the sand is saturated with oil and drainage has not taken place to such an extent that the gas used for repressuring will pass through the sand in large quantities without moving oil to the wells, as frequently occurs when old fields are being repressured.

Also, I believe that development costs can be reduced. To accomplish this some form of unit operation will be necessary, to permit a wider spacing of wells, control of back-pressures and other essential factors. The Seminole field, for example, has been drilled with one well to 10 acres. Suppose this spacing were changed to one well to 20 acres and the wells spaced at equal distances apart with a well for repressuring drilled on a five-spot location; then for 80 acres there would be five instead of eight wells. This would mean an initial saving equivalent to the cost of drilling and equipping three wells, less the cost of installing pressure equipment for repressuring at the five-spot well. I do not believe this equipment would more than equal the cost of one well. The initial net saving would then be equivalent to the cost of two wells. It seems reasonable to assume that by maintaining the pressure the ultimate production would be equal to or greater than that obtained by present methods and at a less cost per barrel.

C. V. Millikan,† Tulsa, Okla.—The decrease in the natural gas-oil ratio when gas-lift is applied while the well is still flowing naturally compares well with the results under similar conditions in the Seminole area.

H. H. Hill,‡ Washington, D. C.—The exceedingly high pressures they are using in California, 1400 to 1500 lb., is particularly worthy of note. I believe that is the only place in the country where such high pressures are being used. It seems to me that there is a field for the engineers to investigate. Probably we shall not encounter those pressures in a great many fields, but often engineers have more or less held back because of the exceedingly high pressures that they did encounter. Mr. Bell has shown very clearly that a decided advantage could be obtained by repressuring in the early life of the field, and I think most of us hope that some day

---

* Production Engineer, Empire Gas & Fuel Co.

† Petroleum Engineer, Amerada Petroleum Corpn.

‡ Chief Petroleum Engineer, U. S. Bureau of Mines.

we can do that rather than let the field be almost depleted and then start in to build up the pressure.

It seems like a decided waste of energy to produce all the gas that is now being produced in some of the new fields and later go back and try to build that field up to somewhat near its original pressure. Mr. Bell gives a very striking example of what can be done in that respect.

C. V. MILLIKAN.—We have recently tried to repressure through a well in the Seminole area where it is necessary to deliver the gas to the well at a pressure of 900 lb. It has not yet had time to show any effect on adjacent wells.

J. B. UMPLEBY,* Oklahoma City, Okla.—I understand that pressures as high as 2000 lb. have been used in California and that pressures of 1800 lb. have been maintained for several weeks. It would be interesting to know the percentage of loss due to leakage.

Repressuring early in the history of a field offers unusual promise of profitable results. I do not suppose anyone knows just how air or gas put in after a field has been depleted expels additional oil from the sand. We can think of it as a pushing effect in part, but I suspect that the more important element is an enlivening effect on the oil. This requires solution in the oil. We know that if gas (or air) and oil are put in contact in the absence of agitation, it will almost take geologic time for the oil to become saturated with the gas by diffusion. If agitation can be provided the result is quickly obtained. This, I believe, is the most fundamental reason for maintaining pressure instead of planning to build up pressure later. I was talking with a nontechnical operator who is repressuring several pools. He said that we are in too much of a hurry for results in repressuring; that it has taken 10 to 20 years to run down the energy in a pool and yet we expect to build it up in a few months. He had, from a nontechnical standpoint, the idea that I am trying to express in terms of diffusion phenomena.

C. E. BEECHER.—I am convinced that agitation or movement of some kind is necessary for gas to diffuse through oil contained within the pores of a sand at a rate sufficiently rapid to be of any value from a production standpoint. I might cite an experiment which will illustrate this point. A steel cylinder, approximately 4-in. in diameter and 30 in. long, was filled about half full of sand, and the sand was then saturated with oil. The cylinder was placed in a vertical position and the void space above the sand was filled with natural gas under a pressure of 250 lb. After a period of two years a sample of oil taken from the bottom of the cylinder was perfectly dead, showing no signs of gas.

F. M. BREWSTER, Bradford, Pa.—Mr. Beecher mentioned putting the pressure on one well. If this gives quicker results, why not pressure four wells and produce from one? What would be the result?

C. E. BEECHER.—My discussion referred to conditions similar to those at Seminole, where the producing sand is found at approximately 4100 ft., and to repressuring during the early life of the field. I do not believe the plan suggested by Mr. Brewster would be practical. The one well could not produce as much oil as the four wells or drain as large an area. The cost of repressuring equipment would probably be too great to consider such a plan. It might, however, be feasible for shallow production found at depths less than 1000 ft.

---

* President, Goldelline Oil Corpn.

Ten Years' Application of Compressed Air at Hamilton Corners, Pa., with Core Studies of the Producing Sand*

By Charles R. Fettke,† Pittsburgh, Pa.

(New York Meeting, February, 1928)

In 1914, the officials of the Brundred Oil Corpn., faced with the problem of introducing new methods to increase production in the old and nearly depleted pools of Venango County, became interested in the Smith-Dunn (Marietta) process which was at that time being tried out in southeastern Ohio and which was already yielding very encouraging results. A license to use the process in Pennsylvania was secured from the owners of the patents. These patents were later declared invalid.

The method was first used in Pennsylvania on a property consisting of about 434 acres, of which 300 are productive, at Hamilton Corners, 15 miles northwest of Oil City, in Cherry Tree and Oakland Townships, Venango County. The producing horizon is the First Sand of the Venango Group. A small oil pool was opened up in this vicinity in 1904. By July, 1916, when the compressed air was first introduced to restore pressure, the production had dropped to a point where it was no longer possible to continue profitable operation. From that time until March, 1927, over 100,000 bbl. of oil have been recovered from the tract. The property is being operated at present by the Brundred Oil Corpn. and Lux. The 1926 production, amounting to 10,650 bbl., was only 400 bbl. short of the maximum reached during any year of the 10-year period that the process has been in operation.

Inasmuch as the Hamilton Corners pool is the first one in Pennsylvania in which the Marietta process was tried out, and the one in which it has been longest in continuous operation, considerable interest attaches to the results obtained.

Through the courtesy of H. D. Brown and W. J. Brundred, officials of the Brundred Oil Corpn., all their data on this operation were made available to the writer in connection with an investigation of rejuvenation methods in the State for the Pennsylvania Geological Survey.

Stratigraphic Position of the Producing Sand

The producing sand at Hamilton Corners is encountered at depths of from 364 to 560 ft., depending on the location of the well and the topog-

* Published by permission of the State Geologist of Pennsylvania.

† Associate Professor of Geology and Mineralogy, Carnegie Institute of Technology, and Associate Geologist, Pennsylvania Geological Survey.

raphy. It has been correlated by the operators of the region as the First Sand of the Venango oil sand group, as defined by Carll.[1] This group belongs to the Conewango formation, which is the westward equivalent of at least a part of the Catskill formation of central and eastern Pennsylvania. It is generally considered to be of Upper Devonian Age, although this is still a debatable question.[2] In a light greenish-gray fine-grained argillaceous sandstone layer, 4.5 in. thick, at the top of the sand in a core from F. Tracy No. 22 well, a number of fragments of marine shells were observed which would seem to indicate that the sand was deposited under marine conditions, although no other fossils, except occasional finely comminuted plant remains, were found anywhere in the main body of sand.

Characteristics of the Producing Sand

The producing sand is made up of three parts, an upper bench, a shale break, and the main pay. The upper bench, which ranges in thickness from 6 to 17 ft., shows considerable variation both vertically and laterally. It consists principally of medium to coarse-grained layers of sandstone with some interbedded shale and occasional thin beds of fine conglomerate. Some of it is cross-bedded. As a rule the porosity is low and very little oil production has come from it. The shale break ranges in thickness from 10 to 29 ft. While consisting mostly of shale, it frequently has interstratified with it numerous thin, very fine-grained, dense sandstone seams of low porosity. The main pay varies in thickness from 14 to 30 ft., averaging about 20 ft. over the entire property. It is made up almost entirely of a fine-grained sandstone, with occasional thin shale partings. While, for the most part, it is comparatively friable and porous, occasionally thin layers occur in it that are very hard and dense. It does not show any cross-bedding.

Detailed sections of the sand as developed in Strawbridge No. 19 and F. Tracy No. 22 wells, obtained from core studies, are shown graphically by the usual conventional symbols in Fig. 1. The location of these wells is given on the property map appearing in Fig. 2. The two cross-sections of Fig. 3, taken at right angles along lines *AB* and *CD* bring out the variation in thickness of the three parts of the sand.

In thin section, under the microscope, the fine conglomerate 6.53 ft. below the top in the core from Strawbridge No. 19 well is seen to be made up largely of quartz pebbles and grains. A few chert and jasper pebbles and an occasional rhyolite pebble are also present. The pebbles are all fairly well rounded while the quartz grains are angular, as shown in Fig. 4.

---

[1] John F. Carll: Geology of the Oil Regions of Warren, Venango, Clarion, and Butler Counties. *Report III*, Second Geol. Survey of Pennsylvania (1880) Plate XI.

[2] C. Butts: Pre-Pennsylvanian Stratigraphy. Report of Topographic and Geologic Survey, Commission of Pennsylvania (1906–08) 199.

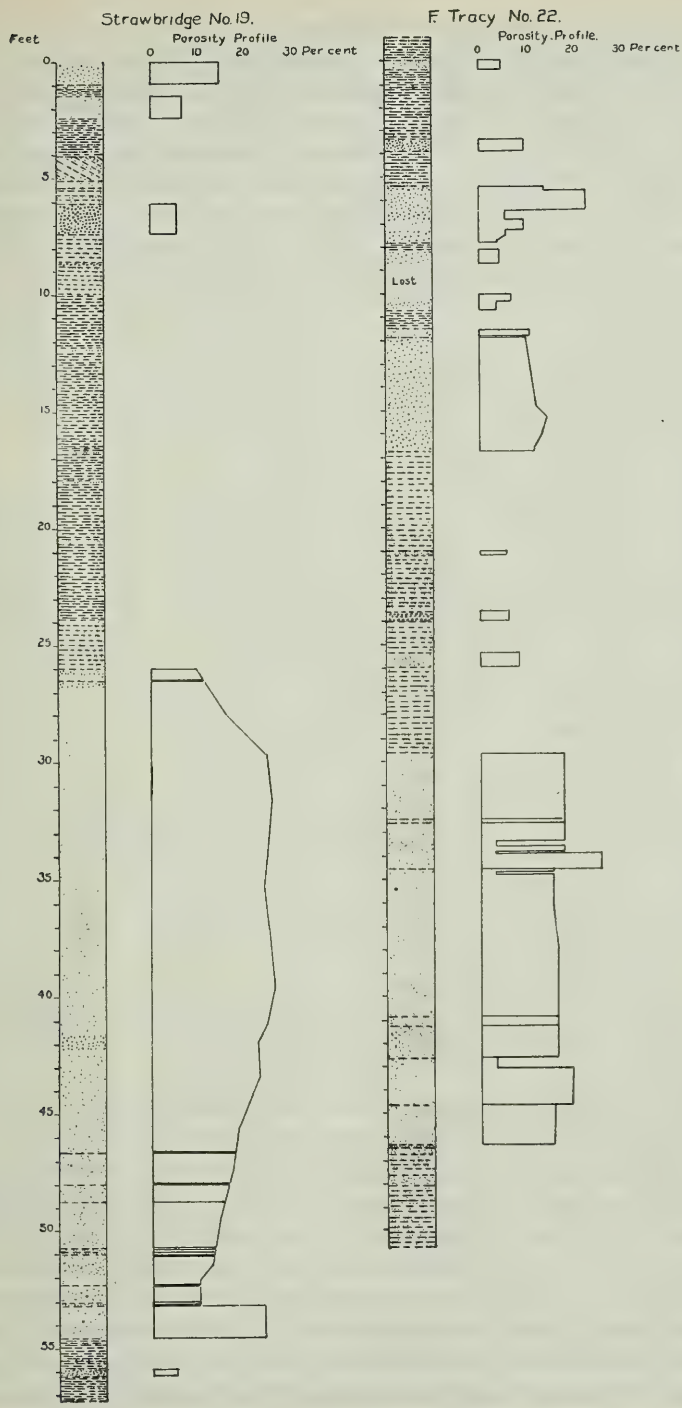


FIG. 1.—SECTIONS AND POROSITY PROFILES OF CORES FROM STRAWBRIDGE NO. 19 AND F. TRACY NO. 22 WELLS.

Heavy minerals are scarce. Those observed are ilmenite, zircon, muscovite, tourmaline and cyanite in decreasing order of abundance. Inasmuch as the sample was treated with hot dilute hydrochloric acid to aid in its disintegration, magnetite, if originally present, probably went into solution. The zircon grains have frequently retained their crystal boundaries, although the majority are at least partially rounded. The largest have lengths of 0.176 mm. and diameters of 0.048. The tourmaline grains are fairly well rounded while the cyanite is angular. Silica, as a

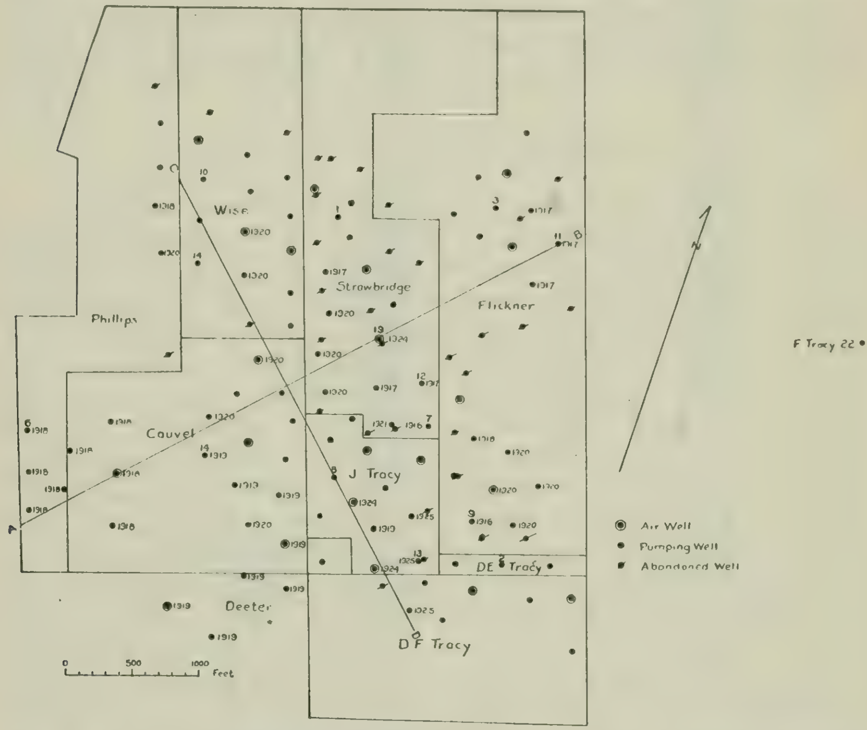


FIG. 2.—MAP OF PROPERTY OF BRUNDRED OIL CORPN. AND LUX AT HAMILTON CORNERS, VENANGO COUNTY, PA.

secondary crystalline outgrowth from the original grains, is the chief bond; calcite occurring only very sparingly between the grains.

The fine-grained sandstone, 39.52 ft. below the top, consists primarily of quartz grains with only an occasional plagioclase grain and a few flakes of muscovite. About 15 per cent. of the quartz grains are fairly well rounded, 45 per cent. are sub-angular, and the remainder angular, as shown in Fig. 5. While heavy minerals are scarce, they are much more abundant than in the fine conglomerate. In decreasing order of abundance, they are ilmenite, zircon, tourmaline, and cyanite; silica and a small percentage of kaolinite or related mineral form the bond. A thin section

from the sandstone, 49.34 ft. below the top, shows very similar characteristics, with the exception that fairly well rounded grains are practically absent, 25 per cent. of its grains being sub-angular and 75 per cent.

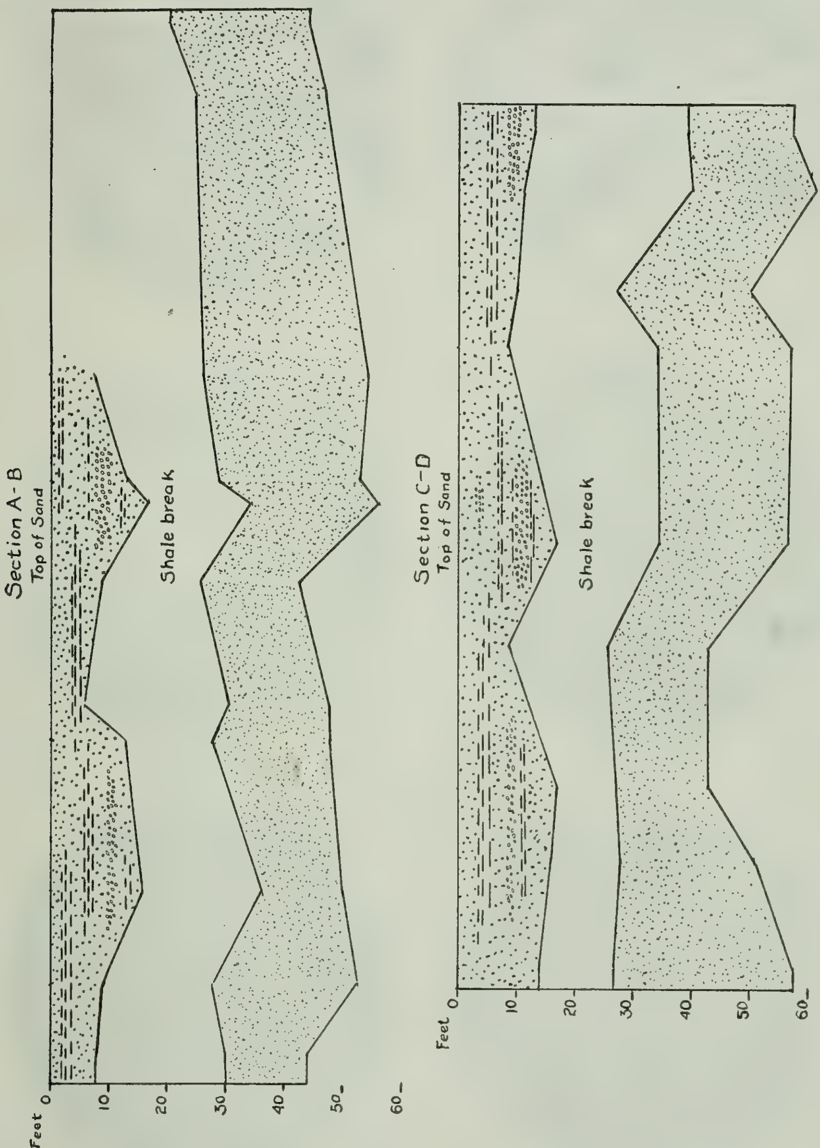
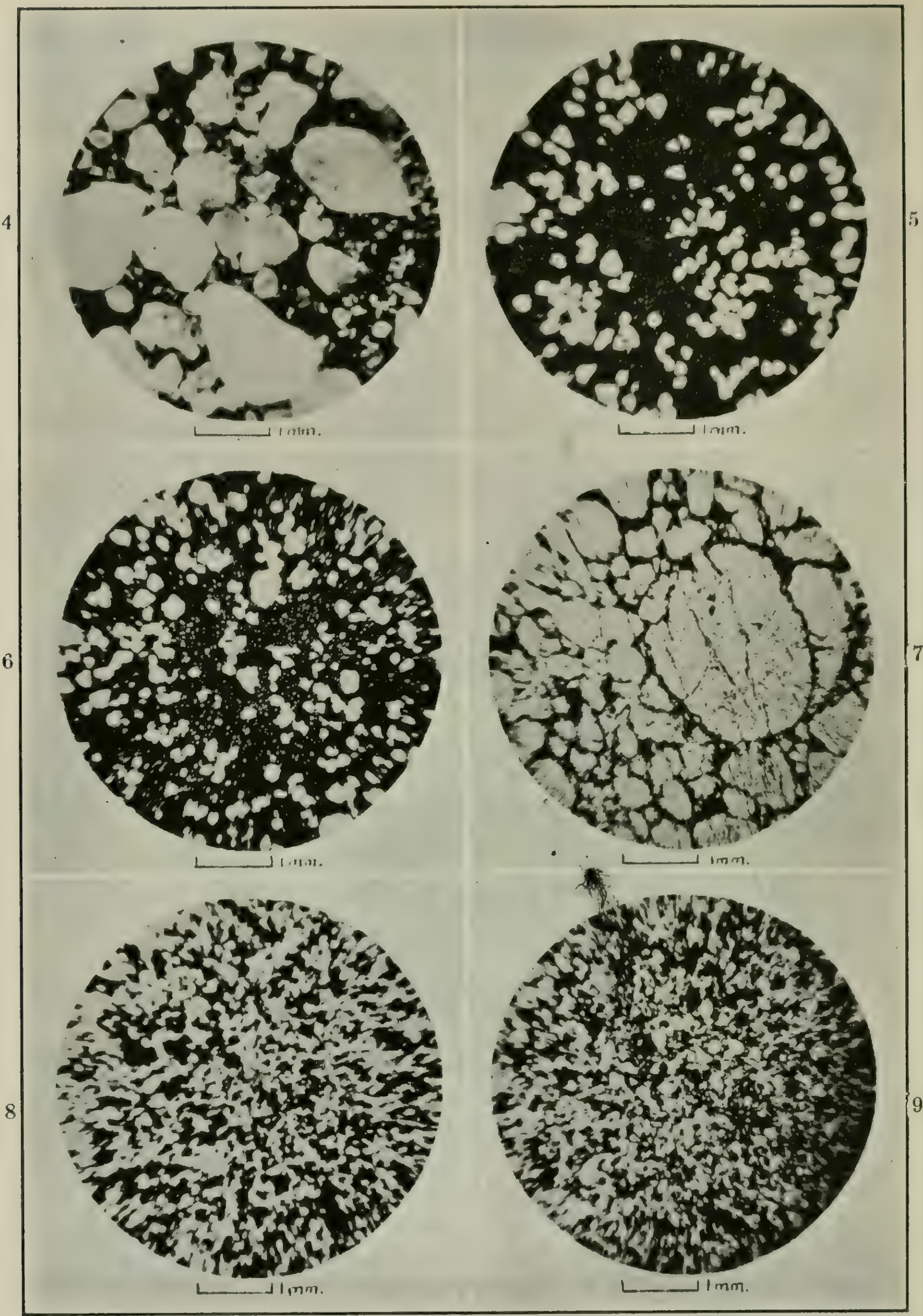


FIG. 3.—CROSS-SECTION OF SAND.

angular, as shown in Fig. 6. Heavy minerals are more abundant although the same in character. A little kaolinite or related mineral is present. There is a larger percentage of silica bond, which occurs as secondary



FIGS. 4–9.—(FOR CAPTIONS SEE PAGE 309.)

crystalline outgrowth from the original quartz grains, and considerable calcite.

Porosity

Table 1 shows the porosities of the sandstone from the cores obtained from Strawbridge No. 19 and F. Tracy No. 22 wells. The determinations

TABLE 1.—*Total Pore Space by Volume in Cores from Two Wells*

Strawbridge No. 19 Well			F. Tracy No. 22 Well		
Depth Below Top of Sand, Feet	Density of Grains	Pore Space by Volume, Per Cent.	Depth Below Top of Sand, Feet	Density of Grains	Pore Space by Volume, Per Cent.
0.20	2.696	14.9	0.19	2.759	4.8
2.37	2.674	6.8	3.61	2.695	9.7
6.53	2.657	5.8	5.50	2.724	13.9
26.10	2.659	10.3	5.76	2.671	22.7
27.92	2.676	16.0	6.63	2.685	5.5
29.64	2.659	24.7	7.07	2.681	9.4
31.54	2.649	25.8	7.47	2.688	5.6
34.13	2.655	24.6	7.74	2.685	3.8
35.23	2.646	24.0	8.42	2.650	4.4
37.07	2.657	25.1	10.17	2.708	6.7
39.52	2.654	26.5	10.51	2.659	3.6
41.05	2.651	24.8	11.66	2.672	10.7
41.90	2.650	22.9	11.94	2.650	9.7
43.29	2.670	23.4	14.91	2.651	12.2
45.52	2.677	18.6	15.28	2.651	14.2
47.38	2.661	17.1	16.03	2.656	13.3
49.34	2.641	14.7	16.63	2.654	11.9
51.41	2.632	12.9	21.09	2.667	5.6
52.16	2.699	10.1	23.62	2.691	6.0
53.61	2.664	24.0	25.49	2.688	8.4
56.00	2.706	5.0	30.91	2.669	17.6
			33.54	2.758	3.1
			34.20	2.667	25.9
			36.07	2.673	15.4
			38.08	2.674	16.2
			43.16	2.673	19.3
			45.49	2.660	15.3

FIG. 4.—SMALL PEBBLES AND GRAINS FROM FINE CONGLOMERATE OCCURRING 6.53 FT. BELOW TOP OF STRAWBRIDGE NO. 19 CORE.

FIG. 5.—GRAINS FROM SANDSTONE OCCURRING 39.52 FT. BELOW TOP OF STRAWBRIDGE NO. 19 CORE.

FIG. 6.—GRAINS FROM SANDSTONE OCCURRING 49.34 FT. BELOW TOP OF STRAWBRIDGE NO. 19 CORE.

FIG. 7.—POLISHED SURFACE OF FINE CONGLOMERATE OCCURRING 6.53 FT. BELOW TOP OF STRAWBRIDGE NO. 19 CORE.

FIG. 8.—POLISHED SURFACE OF SANDSTONE OCCURRING 39.52 FT. BELOW TOP OF STRAWBRIDGE NO. 19 CORE.

FIG. 9.—POLISHED SURFACE OF SANDSTONE OCCURRING 49.34 FT. BELOW TOP OF STRAWBRIDGE NO. 19 CORE.

were made according to the method described by Melcher.[3] They are also shown graphically by porosity profiles opposite the columnar section of the cores in Fig. 1.

The Strawbridge No. 19 core contains 29.7 ft. of sandstone with a porosity of 10 per cent. or more, the average for this portion of the core being 19.9 per cent. The F. Tracy No. 22 core contains 22.1 ft. with an average porosity of 15.6 per cent.

Some idea of the nature of the pores can be obtained from the photomicrographs shown in Figs. 7, 8 and 9, of polished surfaces by reflected light. The specimens were first hardened with bakelite varnish to prevent the tearing out of any of the grains and then polished in the usual manner. The white areas show the quartz grains while the black areas represent the pores. The specimen shown in Fig. 7 was taken at a depth of 6.53 ft. below the top from the Strawbridge No. 19 core; that in Fig. 8 at a depth of 39.52 ft.; and the one in Fig. 9 at a depth of 49.34 ft. They possess porosities of 5.8, 26.5, and 14.7 per cent. respectively.

Size of Grains

Twenty representative samples were selected from different parts of the core from Strawbridge No. 19 well and crushed to individual grain size. A set of Tyler standard screen sieves was used for the mechanical analyses. Table 2, giving the position in the core as well as the porosity of the samples, shows the range in grain size and the variation between different horizons. The screen analyses emphasize the relationship between grain size and porosity, the more porous parts of the sandstone being those that show the greatest uniformity in grain size, as would be expected.

Uniformity Coefficient and Porosity

In order to bring out the relationship between uniformity of grain size and porosity more clearly, the uniformity coefficients as well as the effective sizes of the twenty samples were determined. The uniformity coefficient is the ratio of size of grain that has 60 per cent. of the sample by weight finer than itself to the size which has 10 per cent. finer than itself. The term "effective size" is defined as the size at the point where 10 per cent. of the material by weight is composed of smaller grains and 90 per cent. of larger grains. It is expressed in terms of millimeters. The effective size together with the uniformity coefficient define rather closely the size and uniformity of a sand. The uniformity coefficients,

[3] A. F. Melcher: Determination of Pore Space of Oil and Gas Sands. *Trans.* (1921) **65**, 469.

Texture of Oil Sands with Relation to the Production of Oil. *Bull.* Am. Assn. of Pet. Geol. (1924) **8**, 731.

TABLE 2.—*Screen Analyses of Twenty Samples from Strawbridge No. 19 Core*

Size of Opening, Millimeters		0.20 Ft. Below Top. 14.9 Per Cent. Porosity	2.37 Ft. Below Top. 6.8 Per Cent. Porosity	6.53 Ft. Below Top. 5.8 Per Cent. Porosity	26.10 Ft. Below Top. 10.3 Per Cent. Porosity	27.92 Ft. Below Top. 16.0 Per Cent. Porosity	29.64 Ft. Below Top. 24.7 Per Cent. Porosity	31.54 Ft. Below Top. 25.8 Per Cent. Porosity	34.13 Ft. Below Top. 24.6 Per Cent. Porosity	35.23 Ft. Below Top. 24.0 Per Cent. Porosity	37.07 Ft. Below Top. 25.1 Per Cent. Porosity	39.52 Ft. Below Top. 26.5 Per Cent. Porosity	41.05 Ft. Below Top. 24.8 Per Cent. Porosity	41.90 Ft. Below Top. 22.9 Per Cent. Porosity	43.29 Ft. Below Top. 23.4 Per Cent. Porosity	45.52 Ft. Below Top. 18.6 Per Cent. Porosity	47.38 Ft. Below Top. 17.1 Per Cent. Porosity	49.34 Ft. Below Top. 14.7 Per Cent. Porosity	51.41 Ft. Below Top. 12.9 Per Cent. Porosity	52.16 Ft. Below Top. 10.1 Per Cent. Porosity	53.61 Ft. Below Top. 24.0 Per Cent. Porosity
Through	Caught on																				
6.680	4.699					4.6															
4.699	3.327					0.0															
3.327	2.362			0.4		0.0															
2.362	1.651	0.2		2.3	0.2	0.0															
1.651	1.168	0.1		5.3	0.5	0.1															
1.168	0.833	0.6		10.9	0.1	0.2	0.1	0.2			0.1										
0.833	0.589	7.3	0.1	27.1	0.5	0.4	0.1	1.1	0.1		0.1		0.5	0.3	0.1						
0.589	0.417	20.1	0.1	14.8	3.5	1.7	0.2	1.6	0.2	0.1	0.2	0.1	1.7	3.2	1.3				0.5	0.6	0.1
0.417	0.295	34.1	0.2	15.4	30.3	2.9	1.8	3.5	0.6	0.2	0.8	0.4	8.9	48.5	7.0	0.3		1.8	21.1	21.2	3.2
0.295	0.208	14.6	1.6	9.5	17.8	2.1	8.5	12.2	11.1	1.6	2.6	1.6	7.4	27.4	11.0	1.8	1.2	17.9	27.8	25.0	22.0
0.208	0.147	13.5	29.6	6.9	25.1	34.0	61.2	54.1	68.0	61.8	68.1	60.6	62.7	14.4	35.5	29.6	26.0	28.8	26.2	26.2	34.5
0.147	0.104	5.9	26.2	3.0	11.8	38.3	22.5	21.4	14.7	27.7	22.6	29.9	13.2	5.1	34.2	42.2	43.0	30.5	13.3	13.1	26.3
0.104	0.074	0.7	10.7	0.8	2.1	5.6	2.5	2.8	2.7	4.1	2.4	3.8	1.8	0.9	6.8	13.8	14.6	9.5	4.6	4.3	9.0
0.074	0.061	0.7	9.5	1.1	1.9	2.4	1.0	0.8	0.7	0.8	0.6	1.2	1.0	0.3	1.0	3.6	4.5	3.6	2.2	2.2	1.5
0.061	0.046	0.3	5.7	0.7	1.3	1.7	0.6	0.6	0.5	0.8	0.6	0.7	0.7	0.2	0.6	2.1	2.0	2.2	2.4	1.9	1.0
0.046		0.3	15.1	1.7	3.8	5.3	0.9	0.8	0.6	1.7	0.6	0.3	0.9	0.2	0.9	5.3	7.2	4.3	0.9	3.9	2.4

porosities, and effective sizes of the twenty samples are given in Table 3. Fig. 10 shows graphically the close relationship between the porosities and uniformity coefficients of the samples tested.

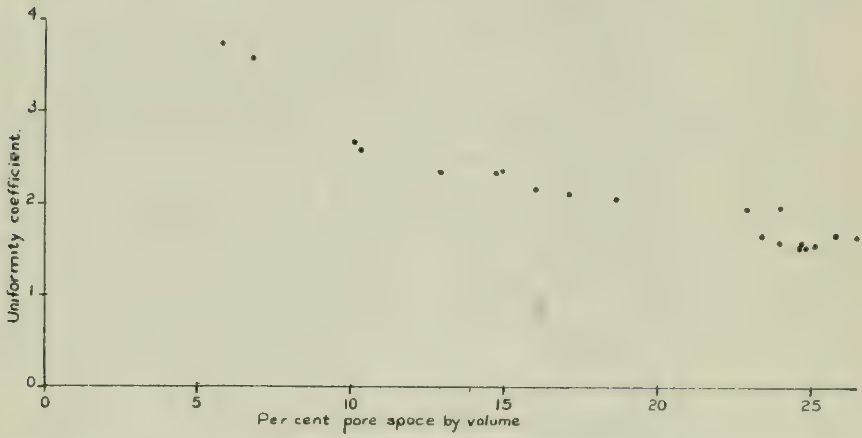


FIG. 10.—RELATION OF POROSITY TO UNIFORMITY COEFFICIENT OF SANDSTONE GRAINS.

TABLE 3.—*Uniformity Coefficients, Porosities, and Effective Sizes of Twenty Samples from Strawbridge No.* 19 *Core*

Depth Below Top of Sand, Feet	Uniformity Coefficient	Porosity, Per Cent.	Effective Size, Millimeters
0.20	2.35	14.9	0.160
2.37	3.58	6.8	0.018
6.53	3.74	5.8	0.172
26.10	2.57	10.3	0.108
27.92	2.14	16.0	0.076
29.64	1.58	24.7	0.116
31.54	1.65	25.8	0.114
34.13	1.52	24.6	0.122
35.23	1.58	24.0	0.110
37.07	1.56	25.1	0.115
39.52	1.64	26.5	0.106
41.02	1.52	24.8	0.125
41.90	1.95	22.9	0.167
43.29	1.64	23.4	0.107
45.52	2.03	18.6	0.070
47.38	2.09	17.1	0.065
49.34	2.32	14.7	0.074
51.41	2.33	12.9	0.103
52.16	2.66	10.1	0.089
53.61	1.97	24.0	0.093

Oil, Gas, and Water Content of the Sand

Eight representative samples, each approximately 4 in. long, were cut from the core of F. Tracy No. 22 well as soon as it was taken out of the core barrel, for the determination of their oil content. The method of procedure was similar to that described in a previous paper.[4] The results are shown in Table 4. The average oil content of the eight samples was only 22 per cent. of their total pore space. Unfortunately, such samples give only an approximate idea of the actual oil content of the sand in the ground. They give a minimum figure, and the actual oil content may be much greater, particularly in very porous open sands, which allow the oil to escape readily. Even with the use of a double-tube core barrel, a certain percentage of oil undoubtedly escapes and is replaced, at least in part, by water. Some evaporation losses also take place while the samples are in storage, and there is a slight unavoidable loss after they are removed from the containers and crushed preparatory to testing.

TABLE 4.—*Oil and Water Content of Eight Samples from F. Tracy No. 22 Core*

Position of Sample in Core, Feet Below Top	Density of Rock	Total Pore Space by Volume, Per Cent.	Total Pore Space Occupied by Oil, Per Cent.	Total Pore Space Occupied by Water, Per Cent.	Total Pore Space Not Occupied by Oil or Water, Per Cent.
14.91–15.24	2.328	12.2	16	69	15
16.03–16.36	2.303	13.3	14	59	27
25.49–25.82	2.462	8.4	34	55	11
30.91–31.24	2.199	17.6	26	45	29
37.75–38.08	2.240	16.2	22	43	35
40.99–41.33	2.240	16.2	22	45	33
43.16–43.49	2.157	19.3	21	40	39
45.49–45.82	2.252	15.3	23	35	42

The wells in the Hamilton Corners pool have produced considerable quantities of gas along with the oil and it is very probable that not all of this gas was originally in solution in the oil. A little salt water is also present in the sand. It would be very difficult, therefore, to estimate just what percentage of the total pore space was originally occupied by oil.

INSTALLATION AND APPLICATION OF AIR PRESSURE

The original compressor plant consisted of a direct-connected 75-hp. gas engine and single-stage compressor. It was started on June 27, 1916. The pressure used ranged from 45 to 60 lb. At the end of 1924, another similar unit was added, thereby doubling the capacity of the

[4] Charles R. Fettke: Core Studies of the Second Sand of the Venango Group from Oil City, Pa. Petroleum Development and Technology in 1926, 228–229.

plant. On Nov. 7, 1925, a fire destroyed the compressor building. The first compressor was started again on December 10 and the other on Jan. 5, 1926. This has been the only serious interruption during the interval since 1916. On March 5, 1926, the pressure was raised to 110 lb., and it is now kept within the limits of 95 to 110 lb. Since July, 1926, the amount of air going into each air intake is being measured periodically, usually at least once in every two months, so that this can be regulated intelligently. Only air has been compressed and introduced into the sand.

At present, 21 wells on the property are equipped as air intakes, 13 of which are old wells drilled prior to the application of the air pressure and 8 are new wells drilled since June, 1916. In preparing the old wells for air intakes, burlap packers are used, cemented just above the sand, as described by Lewis.[5] Two-inch tubing is used. The new wells intended for air intakes are not shot. The packers are placed in the shale break. Sometimes a single one of the hook-wall type and at other times two—a hook-wall and an anchor—are used.

There are 76 pumping wells, 40 of which are old and 36 new. A portion of the new wells have been drilled around the edges of the pool, as shown on the map in Fig. 2, and have extended its boundaries somewhat. The new wells are indicated by the year in which they were drilled.

The map shows the present distribution of the air intakes with respect to the pumping wells. Their number and arrangement have necessarily undergone more or less change from time to time during the interval that has elapsed since the air pressure was first applied. Considerable trouble with by-passing has been experienced. For this reason the lowest pressure that would yield appreciable results has been employed. Only recently, an increase in pressure has become necessary in order to keep up production. It is now necessary to regulate carefully the amount of air going into each well, as there are several on the property which otherwise, at 110-lb. pressure, would be capable of taking the major portion of the entire output of the compressor plant without any commensurate increase in production in the surrounding wells.

On March 5, 1927, 17 of the 21 air-intake wells were taking 351,800 cu. ft. of air, an average of 20,700 cu. ft. per well. The minimum for any one well was 7440 and the maximum, 33,020 cu. ft. Four of the air intakes were shut off.

Production

On the north, west and south, the property includes the limits of the pool, as shown in Fig. 2. On the east, the pool extends a considerable distance beyond, but air pressure has not yet been applied to that part

[5] J. O. Lewi Methods of Increasing the Recovery from Oil Sands. U. S. Bur. of Mines *Bull.* 148 (1917) 43.

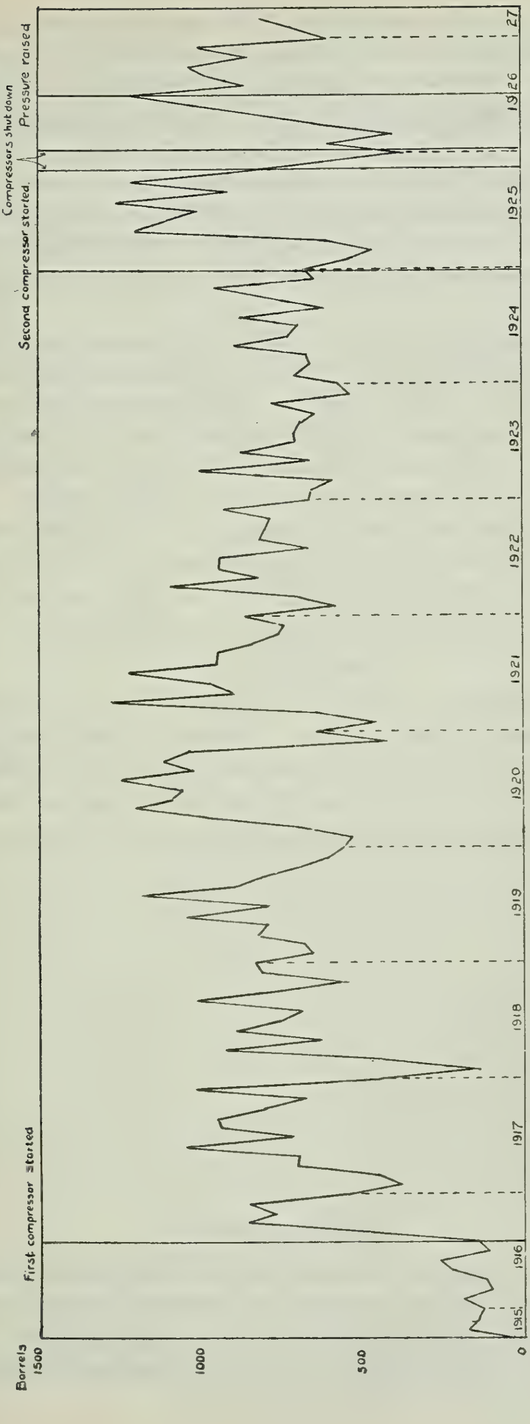


FIG. 11.—GROSS PRODUCTION CURVE BY MONTHS OF BRUNDRED OIL CORPN. AND LUX PROPERTY AT HAMILTON CORNERS, VENANGO COUNTY, PA.

of it. The 300 productive acres on which the air pressure has been used have yielded 102,373 bbl. of oil during the period from June 27, 1916 to March 1, 1927. The gross production in barrels per month for that period is shown by the curve in Fig. 11. The curve brings out the rather marked seasonal variations due to difficulties attending operation during the winter months. The yearly variations have not been so large but in order to keep up this fairly uniform production, a certain amount of new drilling has been necessary, as a study of the map in Fig. 2 will indicate. Also, it has been necessary to increase the compressor capacity and finally the air pressure.

During the last four months of 1915, the average daily production per well of the 38 producing wells then on the property was only 0.1 bbl., while in 1926 the average per well for the 76 pumping wells was 0.4 bbl.

Of the nine leases comprising the property, the J. Tracy has yielded the best results. This lease, consisting of 23 acres, has produced 36,143 bbl. of oil during the period from June 27, 1916 to March 1, 1927, an average of 1571 bbl. per acre. During the 10 months preceding the introduction of the air pressure, the average daily production per well of the nine wells on the lease was 0.1 bbl. In 1917, the average per well had increased to 1.38 bbl. while in 1926 it was still 0.8 bbl.

Gravity of the Oil

Gravity determinations were made on the oil from 13 wells distributed over various parts of the property. The results are given in Table 5 and the location of the wells is shown in Fig. 2. The readings were all taken on the same day on oil as it came from the well and corrected to 60° F.

TABLE 5.—*Gravity of Oil at Hamilton Corners, Pa. in Degrees A. P. I.*

Cauvel No. 14	46.3
Flickner No. 3	44.9
Flickner No. 9	45.5
Flickner No. 11	46.0
Phillips No. 6	45.6
Strawbridge No. 1	44.5
Strawbridge No. 7	44.7
Strawbridge No. 12	46.4
D. E. Tracy No. 2	45.7
J. Tracy No. 8	44.8
J. Tracy No. 13	45.6
Wise No. 10	44.2
Wise No. 14	44.9

Utilization of Gas

The gas from most of the wells has not yet reached the stage of dilution with air at which it cannot be utilized to operate gas engines. It is still used in the engines that drive the pumping powers. Recently, however, it has become necessary to bring some gas from another property to operate the engines at the compressor plant.

DISCUSSION

C. R. Fettke.—My object in taking the gravity readings was to determine, if possible, whether the introduction of the air has had any effect on the gravity of the oil. The gravities are corrected to 60° F. The table gives the number of the well at which each reading was taken and the location of these is shown on the map. While some variation is shown from well to well, oil from wells close to air intakes has practically the same gravity as that at some distance, so that there does not seem to be any evidence on this property that the introduction of the air over a 10-year period has materially changed the gravity of the oil.

C. E. Beecher,* Bartlesville, Okla.—Have you analyzed the gas mixture?

C. R. Fettke.—In the case of some of the wells, the gas has been diluted to such an extent by air that it will no longer burn. . I have not had an opportunity to make any analyses.

---

* Production Engineer, Empire Gas & Fuel Co.

Factors Influencing the Recovery of Petroleum from Unconsolidated Sands by Water-flooding

By L. C. Uren* and E. H. Fahmy,† Berkeley, Calif.

(New York Meeting, February, 1928)

During recent years, oil producers have observed with interest the practical success which has attended the application of water as a medium for displacement of oil from its reservoir sands in the Bradford field of northern Pennsylvania and southern New York. Here, according to various authorities, additional recoveries of from 2,000 to 12,000 bbl. of oil per acre have been secured by this method, after ordinary flowing and pumping methods of production had practically reached the lower limit of economic operation.

Notwithstanding the success which has attended the practical use of the flooding process in the Bradford field, oil producers in other regions are skeptical of its value when applied under physical conditions differing markedly from those which characterize the Bradford field. Its use would probably be construed as illegal in most of the oil-producing states. This general reluctance on the part of oil producers in other regions to accept the flooding process is due in large part to lack of information regarding the factors that influence its operation and efficiency.

With the purpose of clarifying to some extent the issues involved, and of determining when the flooding process may or may not be effectively employed, the writers have conducted a series of laboratory experiments under carefully controlled conditions, designed to indicate the influence of various physical, chemical and lithologic factors. These experiments have not been conducted under conditions identical with those which exist at depths far below the earth's surface, so that direct quantitative comparisons with field results are not justified, but it is believed that the experimental results at least warrant qualitative interpretations that may be applied to field conditions. The methods employed in the conduct of these experiments are briefly explained, and the results, together with the conclusions based thereon, are presented.

Factors Influencing Displacement of Oil from Sands by Water-flooding

Before presenting the experimental data, it will be desirable to consider the manner in which the residual oil is retained within the oil sand

* Professor of Petroleum Engineering, University of California.

† Petroleum Engineer.

and the physical effects that occur when it is displaced by water. With knowledge of the mechanics of flooding, we will then be in a position to study the effects of the several variables which influence the oil displacement.

The water-flooding process is to be regarded as a secondary method of recovery, to be applied only after a portion of the oil originally present in the oil sand has been expelled by the expansion of the associated natural gas. A large part of this natural gas was originally in solution in the oil under high pressure, but on being released from solution by reduction in pressure, it assumes the form of minute gas bubbles distributed through the oil mass.[1] Though these bubbles expand and to a large extent escape from the oil to well outlets, and by gravitational segregation accumulate to form relatively large masses of gas trapped in the oil sand above the surface of the residual oil, it seems probable that the oil remaining in the sand will never be entirely free of occluded gas bubbles. Therefore, after pressure equilibrium is attained within the oil sand, we may conceive of the residual oil as being concentrated in the pore spaces of the lower portions of the reservoir rock, the oil retaining within it a myriad of gas bubbles of all sizes. The upper portion of the reservoir sand remains wet with oil, but contains chiefly gas within its pore spaces, rather than oil. It will be observed that under the conditions described, the oil will be retained primarily by the force of adhesion on the sand grains; also, by capillary attraction between the sand grains, and as films inclosing gas bubbles. There will also be a certain amount of free-draining oil left without motivating force in the sands, by reason of gas drainage.

When water is introduced into a partially depleted oil sand in which the residual oil is held under the conditions described, if applied in such a way as to expel the oil without "by-passing" or "trapping," it may largely displace the free-draining and capillary-held oil; but only to a limited extent will the adherent oil be removed. The free-draining oil and capillary-held oil is merely driven ahead of the encroaching water by a process of physical displacement resulting from its superior pressure and density, aided by the natural immiscibility of the two fluids. It is possible that capillary-held oil may also be slowly displaced by water due to the superior capillary attraction of the sand pores for the latter. Release of oil held to the sand-grain surfaces by adhesion may be accomplished only when the flood water is capable of preferentially wetting the oil-wet sand-grain surfaces. Pure water is ordinarily incapable of doing this, but when certain flooding "agents" are dissolved in the flood water,

---

[1] For a detailed description of the mechanics of expulsion of petroleum from its reservoir rock by expanding natural gas, see an article by L. C. Uren in *Natl. Petr. News* (Jan. 26, 1927).

the equilibrium tension of the oil-water-silica interface may be so altered as to permit of more or less complete displacement of the adherent oil.

Consideration of the mode of displacement of oil from the reservoir sand by water-flooding leads to the expectation that a number of different variables will be found to influence the efficiency of the process. We should expect the size of the sand grains, their porosity and the viscosity of the oil to largely determine the resistance offered to displacement. We know that the interfacial tensions developed between the oil and the flood water, between the minerals composing the reservoir sand and the oil, and between these same minerals and the flood water, must be important factors in determining the extent to which the oil will be retained on the sand grains by adhesion, and between the sand grains by capillarity. Modification of these interfacial tensions by contact with gas bubbles will probably also be found to have an influence on release of the oil from the sand grains, and in the subsequent movement of oil through the sands, these gas bubbles will again have an important effect. Temperature will be found to be a factor, since it influences the oil viscosity to an important degree, and also, to some extent, the interfacial tension relationships. Capillary effects and readjustments due to operation of interfacial forces require time in reaching equilibrium, and we may therefore expect to find that the rate of advance of the flood water through the reservoir sand will be a factor in determining the efficiency of oil recovery. The rate of advance, in turn, is dependent on the pressure applied to the flood water; or rather, on the differential pressure operative in moving the fluids through the sands. This differential pressure, of course, is an expression of the superiority of the pressure of the flood water in comparison with the resistance to movement offered by the reservoir sand.

The laboratory experiments, results of which are summarized in the sections following, have been planned to determine the extent to which the more important of these different factors influence the efficiency of oil recovery by water-flooding. The data are, as yet, incomplete, but enough have been assembled to permit of drawing certain conclusions which will be of interest in forecasting whether or not the flooding process will be effective under a given set of field conditions.

Materials and Equipment Used in the Flooding Experiments

The sand used in most of the experiments was a clean, white beach sand, containing but a few per cent. of minerals other than quartz. In order that the influence of grain size might be properly interpreted, all experiments were performed with carefully sized sands. The tests were conducted throughout with unconsolidated sands containing no cementing material whatever. Porosities were therefore high, though this factor

could be controlled within certain limits by varying the degree of compaction of the sand.

The oils employed in the flooding tests were crude petroleum from the following sources and having the properties indicated:

Oil No.	Source	A. P. I. Gravity	Saybolt Universal Viscosity at 65° F., Seconds
1	Santa Fe Springs, Calif.	31.5	80
2	Los Angeles Basin, Calif.	24	156
3	San Joaquin Valley, Calif.	15	6,000
4	Tonkawa, Okla.	41.5	53

Oil No. 2, a California, asphaltic base oil of medium density and viscosity, was used in most of the experiments.

The flooding medium employed was either water or a water-solution of some solute which, it was thought, might confer special properties. A number of tests were made with distilled water, primarily to establish a standard of comparison. Successive tests with various water solutions were then made, and in order to permit of some measure of comparison, the solutions were customarily diluted to one-tenth normal. In some cases, where the reagents appeared to possess special properties, tests were made with more dilute or more concentrated solutions.

The experiments were conducted in glass-walled containers about 16 in. high and 2½ in. in diameter, of the form sketched in Fig. 1. Sands were packed in the containers by carefully tamping to the desired porosity, the sand being moistened with oil as introduced. After charging with sand and oil, the ends of each flooding "tube" were fitted with rubber stoppers, sealed to the glass container with molten paraffin. Glass tubes penetrating these stoppers permitted the flood water to enter at the bottom and the displaced oil to overflow at the top into a graduated receiving cylinder. Several of these containers, connected with a common water reservoir, as illustrated in Fig. 1, permitted as many tests concurrently under similar conditions.

The sand compacted in the tubes was in all cases practically saturated with oil before the flood water was admitted. In the process of filling the tubes with oil-wet sand, it was found that many air bubbles were occluded, which could only be removed with difficulty, so that the pores of the sand would be left incompletely saturated with oil. In order to avoid this, in many of the experiments, only enough oil to moisten the sand was introduced as the sand was tamped in the tubes, and after the corks had been inserted, additional oil was drawn in through the lower ends of the tubes by applying suction from a vacuum pump at the upper end. This method results in practically complete saturation of the sand.

In order to standardize the rate of progress of the flooding reagent through the sand, the elevation of the flooding reagent reservoir was given special attention, and was frequently adjusted to maintain the desired static head. This head was measured and recorded for each experiment. Capillarity provides an additional upward pressure aiding the flood water in displacing the oil from the sand. This capillary head was also carefully measured and taken into consideration in computing the effective displacement pressure.

With the apparatus and materials described, two series of tests were made. In one set of experiments, a small static pressure was maintained

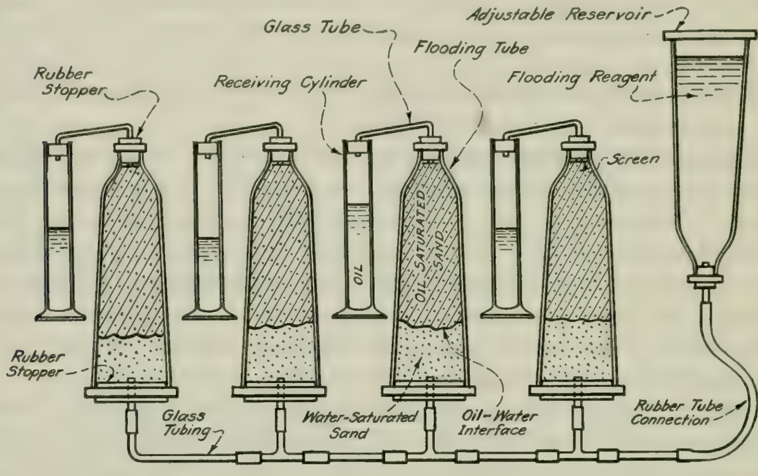


FIG. 1.—ARRANGEMENT OF APPARATUS USED IN FLOODING TESTS.

on the flooding medium by elevating the water reservoir to from 1 to 10 in. above the oil-overflow tube. This pressure resulted in a slow rate of progress of the flooding medium through the sand, giving it time to react both physically and chemically. In these tests, from 5 hr. to as much as 27 days, in extreme cases, were required for the flood water to reach the overflow tube. The second series of tests were performed more rapidly, a vacuum pump connected to the overflow tube, promoting rapid advance of the flooding medium through the sand. Such tests were completed in from 30 min. to 1 hr. The experiments were closely watched and observations made at least twice daily. The fluid levels were at all times maintained as constant as possible by frequent readjustment of the level of the flooding medium in the reservoir.

Influence of Size of Sand Grains on Flooding Efficiency

The size of the mineral grains composing the oil sand has an important influence on the percentage recovery in flooding. Finer grained sands,

generally speaking, have smaller pore openings than coarser sands, and they therefore offer greater resistance to the passage of fluids through them. Finer grained sands also show a greater tendency to flood irregularly, the flood water seeking the channels of lesser resistance and by-passing lenses or irregularly shaped bodies of oil sand that may be left completely saturated. The data presented in Table 1 show, in all but one instance (the result of which is questionable), a decrease in the percentage recovery with diminution in the size of the sand grains.

TABLE 1.—*Results of Tests Showing Influence of Sand-grain Size on Flooding Efficiency*

Distilled Water was the Flooding Medium. No. 2 Oil Was Used Throughout

Size of Sand Grains, Mesh	Approximate Time of Test, Days	Porosity of Sand, Per Cent.	Hydrostatic Head Maintained, Inches	Percentage Recovery
20 to 40	2	45.0	6	41.3
40 to 60	5	42.3	6	30.0
60 to 80	3	43.0	6	34.2
80 to 100	6	45.0	6	33.0
100 to 120	7	41.6	14	27.4
150 to 200	7	45.4	14	9.6

EFFECT OF SAND POROSITY ON FLOODING EFFICIENCY

Porosity of the reservoir sand is found to be one of the most important factors influencing the efficiency of recovery by water-flooding, the percentage recovery diminishing as the porosity decreases. This is a natural result of the more compact arrangement of sand grains, with consequent reduction in size of the openings between grains attending a condition of low porosity. The data of Table 2 will serve to indicate to what extent porosity influences recovery. Conditions were identical with those of the tests recorded in Table 1, except for the sand porosity.

TABLE 2.—*Results of Experiments to Determine Influence of Sand Porosity on Flooding Efficiency*

Distilled Water was the Flooding Medium. No. 2 Oil Was Used

Size of Sand Grains Mesh	Porosity of Sand, Per Cent.	Percentage Recovery
40–48	41.1	37.5
40–48	35.0	32.5
40–48	29.1	22.2

EFFECT OF CAPILLARITY IN WATER-FLOODING

Some authorities have expressed the opinion that the displacement of oil by water in water-flooding is due to a capillary effect induced by the

superior surface tension of water in comparison with that of oil. The experimental results presented in Tables 1 and 2 apparently disprove this theory. Fine sands and sands of low porosity, generally speaking, have smaller pore openings than relatively coarse-grained and more porous sands. Inasmuch as capillarity is a force of greater magnitude in small pore openings than in large,[2] we should expect more efficient displacement of the oil in the finer and less porous sands. The reverse, however, is apparently true, greater recoveries being secured from the coarse-grained and more porous sands. We may therefore conclude that capillarity does not play an important role in water-flooding.

Effect of Physical Properties of the Oil on Flooding Efficiency

The viscosity, surface tension and density of the oil have an important influence on the percentage recovery possible from an oil sand by water-flooding. The efficiency of recovery rapidly diminishes as the viscosity and density of the oil increases. Though the flooding process depends to a certain extent on the difference in density existing between the flood water and the oil, it is thought that the higher viscosity characteristic of the heavy oils is of far greater importance from the standpoint of flooding efficiency than any difference in density which may exist. The surface tension of the oil and its interfacial tension against water and silica undoubtedly also have an important influence, and different oils are found to vary somewhat in these respects. Inspection of the data of Table 3 will give a general idea of the combined influence of viscosity, density and interfacial tension on flooding efficiency.

Table 3.—*Results of Experiments to Determine Influence of Oil Viscosity, Density and Surface Tension on Flooding Efficiency**

Distilled Water was the Flooding Medium

Character and Source of Oil	A. P. I. Gravity	Viscosity, Saybolt Sec. at 65° F.	Interfacial Tension between Oil and Distilled Water, Dynes	Recovery, Per Cent.
Motor gasoline (California)	54.5	30	19.9	67
Oklahoma crude	41.5	53	12.6	73
Santa Fe Springs, Cal., crude	31.5	80	16.3	60
Los Angeles Basin, Cal., crude	24.0	156	17.5	20
Kern River, Cal., crude	15.0	6000	18.6	2

* A 40 to 48-mesh sand was used in each of these experiments, and the porosity was maintained at as nearly the same percentage as feasible in each case.

The influence of surface tension on recovery is brought out by a comparison of the flooding tests made with commercial gasoline and

[2] L. C. Uren and A. H. El-Difrawi: Capillary Retention of Petroleum in Unconsolidated Sands. Petroleum Development and Technology in 1926, 70.

Oklahoma crude. Though the crude has a greater viscosity and density, the recovery obtained with it is superior to that obtained with gasoline, apparently because the interfacial tension developed by gasoline against water is greater than that of the oil.

Effect of Temperature on Flooding Efficiency

Moderate increase in temperature will produce important reductions in the viscosity of petroleum, and as has been shown in the previous section, low viscosity is conducive to high recovery in the flooding process. Aside from this, increased temperature will result in a reduction in the surface tension of the oil, thus increasing the interfacial tension between the sand and the oil, and thereby promoting the release of the latter. The interfacial tension between the flood water and the oil is also reduced by increase in temperature, and thus two phases of the system will be favorably influenced toward release of the oil.

Again, from the chemical standpoint, if a flooding agent such as sodium carbonate is used, the reactions between silica and the flooding agent proceed more rapidly as the temperature is increased. There is also less tendency for the products of the reaction to precipitate and clog the pores of the sand.

With the expectation that a considerable increase in flooding efficiency would result by conducting experiments under elevated temperature, a steam-jacketed flooding tube was constructed and a number of experiments[3] performed at temperatures ranging from 70° to 125° F. The results were somewhat disappointing, only minor recovery increases being secured. The increase was nothing more than might have been expected from the reduced viscosity of the oil at the elevated temperatures used. Table 4 gives the results.

Table 4.—*Results of Experiments to Determine Influence of Temperature on Flooding Efficiency*

Distilled Water was the Flooding Medium

Porosity of Sand, Per Cent.	Temperature of Oil, Water and Sand, Deg. F.	Recovery, Per Cent.
39.1	125	70.5
38.7	120	69.8
34.1	110	61.3
36.7	70	60.4

[3] These experiments were performed by S. H. Pope, a senior petroleum engineering student at the University of California, and reported in his thesis: The Water-flooding of Oil Sands (May, 1927).

Influence of Dissolved Salts in Flood Water on Flooding Efficiency

Several investigators have reported that certain water-soluble salts, when dissolved in the flood water, have an important effect in releasing oil held by adhesion on the sand grains.[4,5,6] The beneficial effect resulting from the use of these reagents has been found to be primarily due to changes in the interfacial tension relationships between the oil, water and mineral grain surfaces. Well-established physical laws indicate that release of the adherent oil from the sand grains would be promoted by decreasing the interfacial tension between the flood water and the mineral of which the sand grains are composed; or by increasing the interfacial tension between the oil and the mineral composing the sand; or, by decreasing the interfacial tension between the oil and the flood water.

For release of adherent oil from oil-wet sand grains, the interfacial tension between the oil and the mineral composing the sand must be greater than the sum of the interfacial tensions between the water and the mineral and between the flood water and the oil.[7] Sodium carbonate is an effective flooding agent, because it hydrolyzes in water, forming sodium hydrate, which attacks silica, thus reducing the interfacial tension between the water and the mineral-grain surfaces to zero; and it is also found to have a similar effect on the interfacial tension between the flood water and the oil, possibly due to some obscure reaction with certain constituents of the oil.

A series of flooding experiments was performed with various solutions of water-soluble flooding agents, which confirm this theory; particularly that part of it which deals with the effect of decreasing the interfacial tension between the oil and the flood water. The effect of sodium carbonate, sodium silicate, sodium hydrate, sodium bicarbonate, sodium borate, alum, hydrochloric acid, acetic acid, sodium acetate, phenol, carbonic acid and sodium chloride, were all tried in turn and their relative value as flooding agents determined. A method was also devised, with the aid of the De Nouy tensiometer, for obtaining comparative measurements of the interfacial tension between these solutions and the oil used. In a long series of experiments with the different reagents mentioned, it was consistently found that substances which reduced the oil-water inter-

---

[4] E. Fyleman: The Separation of Adherent Oil or Bitumen from Rock. *Jnl. Chem. Ind.* [London] (1922) **41,** 14T.

[5] P. G. Nutting: Chemical Problems in the Water-driving of Petroleum from Oil Sands. *Ind. & Eng. Chem.* (Oct., 1925) **17,** 1035.

[6] R. C. Beckstrom and F. M. VanTuyl: The Effect of Flooding Oil Sands with Alkaline Solution. *Bull.* Am. Assn. Petr. Geol. (March, 1927) **2,** 223.

[7] For an explanation of the influence of these interfacial tensions on the release of adherent oil on silica sand grains, see an article by L. C. Uren in *Natl. Petr. News* (Aug. 3, 1927).

facial tension also increased the efficiency of recovery of oil from the sand by flooding. The relationship existing between the interfacial tension and percentage oil recovery is well brought out by the graphs of Fig. 2, which also indicate the relative value of the various reagents used from the standpoint of flooding efficiency.

The results of these experiments indicate that the strongly alkaline reagents, or those which are dissociated by water to form strongly alkaline solutions, have the property of releasing the adherent oil developed to the highest degree. Sodium hydrate is probably the most effective of all of the reagents used, but due to its rapid consumption through its reaction

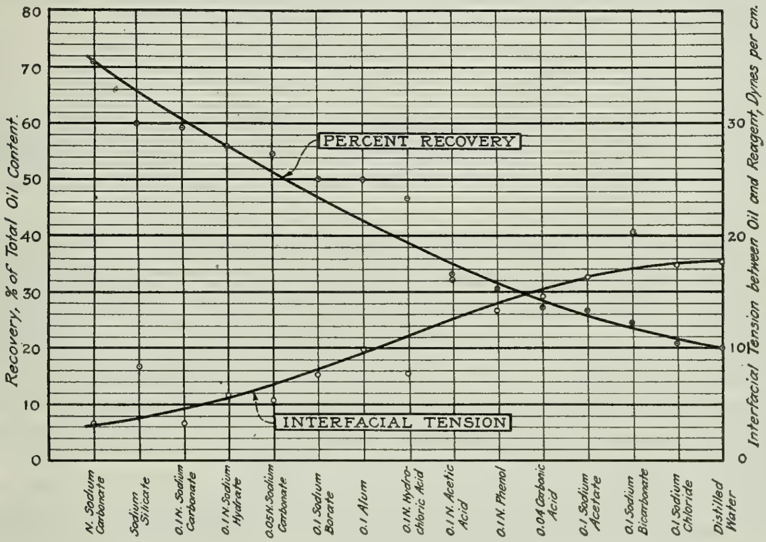


FIG. 2.—COMPARISON OF PERCENTAGE RECOVERY WITH INTERFACIAL TENSION BETWEEN OIL AND FLOODING REAGENTS.

with silica, it gives a somewhat lower over-all recovery throughout the 16-in. length of a flooding tube than sodium carbonate or sodium silicate, which offer a higher degree of "protective alkalinity." The acids and acid salts are found to be less effective than the alkaline salts, but all assist flooding to some extent: that is, a better recovery is effected through their use than is possible with distilled water. It is noteworthy that sodium chloride, a reagent commonly present in oil-field ground waters, and sodium bicarbonate, a product formed by the reaction of sodium carbonate on silica, are the least effective of all of the reagents tried.

While the interfacial tension between the oil and flood water has an important influence in determining the efficiency of recovery, it is probable that chemical reaction of the dissolved salt on the silica, of which most sands are primarily composed, is of greater importance in releasing

the adherent oil. Reaction of the flooding agent with the silica of the sand reduces the interfacial tension between the mineral and the flood water, increases the wetting power of the flood water for the mineral, and thus promotes release of the oil. We have no means of measuring solid-liquid interfacial tensions, but they are thought to be generally higher than liquid interfacial tensions. When the solid dissolves in the liquid, we know that the interfacial force must be approximately zero; hence an important change in interfacial tension relationships tending to release the oil is indicated, though we cannot quantitatively measure its influence. It is found on inspection that the reagents giving the higher efficiencies are also those which are strongly ionized and react with silica. The following chemical reactions are typical of those which occur:

$$Na_2CO_3 + SiO_2 \rightarrow NaOH + NaHCO_3 \rightarrow NaHSiO_3 + NaHCO_3$$
$$NaOH + SiO_2 \rightarrow NaHSiO_3$$
$$Na_2B_4O_7 + SiO_2 \rightarrow NaOH + NaHB_4O_7 \rightarrow NaHSiO_3 + NaHCO_3$$
$$Na_2SiO_3 + 2SiO_2 \rightarrow NaOH + H_2SiO_3 + 2SiO_2 \rightarrow NaHSiO_3 + H_2SiO_3$$

Water, H_2O, is supposed to be in contact with the reagents in each of the above reactions.

Inspection of the recoveries indicated in the graphs of Fig. 2 shows that the alkaline salts are more effective than the strongly acid salts, the latter being scarcely more effective than pure water. Divalent salts of the weak acids, however, are effective after hydrolyzing, but univalent salts of the weak acids are less effective. Neutral salts have little if any effect. The probable reason for the lower efficiency of the acidic solutions is found in the fact that the silica dissolves less readily in acids than in alkalies.

Effect of Changing Texture of Sand on Efficiency of Water-flooding

It has been shown that fine-grained sands and less porous sands offer greater resistance to the passage of fluids than relatively coarse-grained and more porous sands. In nature, sand strata of uniform texture extending over great areas are uncommon. Generally, lenticular bodies of finer or coarser material will be included within the oil-bearing stratum, as a result of cross-bedding or other irregularities of deposition. Clay or shale partings, which are almost impervious to the passage of fluids, may be deposited between various component strata of the reservoir sand, thus to a considerable degree restricting free passage of oil, gas and water. It is logical to expect that such conditions may have an important influence in limiting the percentage recovery possible by water-flooding under field conditions.

Several experiments were performed to secure some measure of the quantitative effect of variable sand texture. Three different flooding

tubes were prepared, one of which contained equal proportions of 20 to 28 mesh, 40 to 48 mesh, and 60 to 65-mesh sand, all thoroughly mixed. Another was filled with alternating layers 1 in. thick, of the three sand sizes, while the third tube was entirely filled with 40 to 48-mesh sand. The sands in the three tubes were saturated with 24° oil (oil No. 2) and then flooded with a one-twentieth normal solution of sodium carbonate. Table 5 gives the results:

TABLE 5.—*Experiments to Determine Effect of Mixed and Stratified Sands of Variable Grain Size on Flooding Efficiency.*

Size and Condition of Sand	Average Porosity, Per Cent.	Percentage Recovery
Equal volumes of 20–28, 40–48 and 60–65 mesh sands, thoroughly mixed	35.9	44.2
Alternating layers of 20–28, 40–48 and 60–65 mesh sands	35.6	48.4
All 40–48 mesh sand, well compacted	37.0	54.8

While the over-all recoveries obtained in these tests did not vary greatly, visual inspection of the tubes after flooding indicated that the flooding effect was quite irregular in the first of the three experiments in which a mixture of the sands of different grain size was used; while in the case of the stratified sands of different sizes, the oil tended to accumulate —*i. e.*, recovery was less complete—where it was necessary for the oil to pass from a layer of coarse sand into one of finer texture. It seems clear that variable texture of sand grains results in a reduction of flooding efficiency, in comparison with what is possible in sands of uniform grain size.

Effect of the Time Element on Efficiency of Water-flooding

The rate at which the flood water advances through the sand has an important influence on the efficiency of recovery by water-flooding. Physical and chemical reactions do not come to equilibrium instantaneously. Where one liquid replaces another by a process of readjustment in interfacial tensions, the process is necessarily a slow one. If it is hastened by artificial means, a lower recovery than would otherwise be possible is likely to ensue.

One method by which the flow of water into an oil-saturated sand may be hastened is that of applying additional pressure to the flood water, and the rate of progress is found to be some function of the pressure applied. Up to a critical point, additional pressure is helpful in securing the ultimate production within a briefer interval of time; but when a rate of advance is attained at which the flooding agent has

insufficient time to bring about efficient displacement of the adherent oil, the added pressure becomes uneconomic. It is important, in practical flooding operations in the field, to know to what extent the rate of flow of the fluids may be increased without serious loss in efficiency of recovery.

Several experiments were made with various flooding reagents to determine the influence of time on the efficiency of recovery. In some instances, the static head on the flood water was only a few inches; in other cases, a powerful vacuum was applied on the delivery tube to hasten displacement of the oil. In practically every case, a reduction in the ultimate recovery resulted through the use of a rapid drive in comparison with recovery in equivalent experiments under low static head. Rapid displacement of the oil also resulted in formation of considerable emulsion in several instances. Table 6 gives the results of experiments planned to determine the relative recoveries by slow and rapid flooding.

TABLE 6.—*Results of Experiments to Determine Influence of Rate of Flooding on Displacement of Oil*

Flooding Reagent Used	Percentage Recovery	
	Slow Flooding	Rapid Flooding
Sodium chloride (0.1 N.)	20.6	8.0
Alum (0.1 N.)	50.0	28.0
Hydrochloric acid (0.31 N.)	46.6	18.0
Sodium hydrate (9.1 N.)	56.0	47.0
Sodium carbonate (0.1 N.)	59.0	42.5

EFFECT OF SAND-GRAIN COATINGS ON FLOODING EFFICIENCY

If the greater efficiency of the alkaline flooding agents is due to their chemical action on silica, as shown in a previous section of this paper, it follows that grain coatings not reactive with the flooding agent and preventing its contact with the silica, would tend to reduce the efficiency of flooding. If so, this would seem to be a matter of considerable importance from the practical standpoint, inasmuch as sands are commonly coated in nature with secondary minerals such as calcium carbonate, iron oxide and various siliceous substances.

In order to determine the effect of such grain coatings, four portions of a clean white silica sand of 40 to 48 mesh were selected. The first was saturated with oil No. 2 for three months, then partially washed with gasoline and dried over Bunsen burners until a black carbon coating was formed on the sand grains. This coating was hard and vitreous in appearance and was practically insoluble in gasoline. The second portion

of sand was saturated with a solution of sodium carbonate and then stirred in a solution of calcium chloride. The excess liquid was then decanted off and the sand washed with water and dried. A thin coating of calcium carbonate on the sand grains resulted. The third portion of sand was treated with ferric chloride and ferric hydroxide precipitated on the sand grains by adding sodium hydroxide. After decanting off the excess fluid and washing, the sand was thoroughly dried, thus converting the ferric hydroxide into red oxide of iron. The fourth portion of sand was used without treatment.

These four sands were charged into separate flooding tubes, saturated with 24° California crude, and flooded with one-twentieth normal sodium carbonate solution. Table 7 gives the percentage recovery obtained in each case. It will be noted that the sands coated with carbonate and iron oxide gave a much lower yield than the pure silica, but that the carbon-coated sand gave a more complete recovery by flooding. The superior recovery with the carbon-coated sand is possibly due to the lesser resistance offered by the smooth, glasslike carbon surfaces, or it may be due to a change in the angles of contact of the water and oil on the sand-grain surfaces. The tests indicate that comparatively low recoveries may be expected from oil sands containing secondary calcium carbonate or iron oxide, in comparison with what is possible from clean silica sands.

Table 7.—*Results of Experiments to Determine Influence of Secondary Mineral Grain Coatings on Flooding Efficiency*

Nature of Sand Coating	Percentage Recovery
Carbon coating	84
Iron-oxide coating	26
Calcium carbonate coating	25
Clean silica sand	59.5

Influence of Gas Bubbles in the Oil on Flooding Efficiency

Observation, through the glass walls of the flooding tubes, of gas bubbles occluded within the oil and imprisoned within the sand pores shows that they impede the progress of the flood water, and often lead to irregular flooding effects, due to inability of the water to displace or flow by them. Such gas bubbles offer considerable resistance to the passage of fluids through the sand, since they must be compressed and expanded at each pore restriction, and energy is consumed in so doing.

When inundated with water, the gas bubbles remaining in the sand seem to retain a film of oil about them, the thickness of which apparently depends chiefly upon the viscosity of the oil. In sands containing many

gas bubbles, it seems probable that a large part of the oil unrecoverable by water-flooding is so retained. After inundation with water, if sufficient pressure is applied to cause these bubbles to move, they carry their enclosing oil films with them, and these films appear to have the power of scavenging a certain portion of the adherent oil left on the sand grains. They may be observed to grow in thickness as the bubbles advance through the sand. It seems probable that the introduction of a fourth element (gas in the form of bubbles) into the three-phase system of water, oil and silica, has the effect of materially altering the interfacial tension relationships that have been shown to apply in the three-phase system; and in the four-phase system, the gas apparently has a powerful attraction for the oil, which may be a determining factor in increasing ultimate oil recovery if the gas can be caused to move.

Conclusions

The experimental data presented in the foregoing sections would appear to justify the following conclusions:

1. Water-flooding is more effective in coarse-grained sands and in sands of high porosity than in fine-grained sands or sands of low porosity.

2. Capillarity is not a controlling factor in the process of water-flooding.

3. Variable texture of sand grains results in a reduction of flooding efficiency in comparison with what is possible in sands of uniform grain size.

4. Coatings of secondary minerals on sand grains may influence flooding efficiency to an important degree. Calcium carbonate and iron oxide coatings are particularly detrimental in this respect.

5. Flooding efficiency decreases markedly as the viscosity of the oil increases.

6. Some oils have higher surface tension than others, but those having the lower tensions can be more effectively displaced from sands by flooding.

7. Temperature influences flooding efficiency, primarily by reason of its effect on the viscosity and surface tension of the oil.

8. A slow rate of advance of the flooding medium through the oil sand results in greater recovery of oil than is possible by rapid displacement.

9. A definite relationship exists between the interfacial tension of the oil against the flooding medium and the percentage recovery obtained by flooding. The efficiency of flooding increases as this interfacial tension decreases.

10. Certain water-soluble salts, when dissolved in the flood water, have an important effect in releasing oil held on the sand grains. Experiments made with a variety of different chemical substances in solution in

the flood water indicate that alkaline salts are more effective than the strongly acid salts, the latter being scarcely more effective than pure water. Divalent salts of the weak acids are effective to a lesser degree, after hydrolyzing, than the alkaline salts, and univalent salts of the weak acids are still less effective. Neutral salts have little if any effect.

11. The alkaline reagents apparently are effective in every case, due to the action of hydroxides produced by hydrolysis of the dissolved salt. The hydroxyl ion is active in attacking silica, forming acid silicates which are soluble in the flood water. It is in part due to reduction in the interfacial tension between the flood water and the mineral of the reservoir sand, as a result of this reaction, that the flooding reagent owes its ability to release the adherent oil.

DISCUSSION

J. B. Umpleby,* Oklahoma City, Okla.—Professor Uren is to be commended for his effort to define the criteria by which sands favorable for water flooding may be recognized. It is an interesting fact, however, that the Bradford field, in which water-flooding is most successful, is characterized by very fine sand—about one-half the diameter of the Bartlesville sand—yet Professor Uren gets his best results in coarse beach sands.

J. B. Newby,† Bradford, Pa.—In the second table, in which sand of a uniform size is used, and it is by making it more compact that the varying porosity results, does that mean larger sized pores in the case of the larger porosity, and smaller sized pores in the case of the smaller porosity? If so, might not that rather than the percentage of pore space, be the controlling factor in the recovery?

F. J. Fohs,‡ New York, N. Y.—Have some practical results been obtained that will give a measure of comparison with these laboratory results?

J. B. Newby.—One other thing, and that is the decreased recovery as shown in Table 1. It is shown that the recovery drops from 41.3 to 9.6. The 9.6 recovery is with a mesh size which perhaps is comparable to the average for the Bradford sand. As a matter of fact, the recovery at Bradford has been quite commonly as high as 6000 bbl. per acre. The oil in the sand is about 30,000 bbl. per acre, as established by the work of Melcher. This would give a recovery of about 20 per cent. Recoveries have been obtained as high as 8000 bbl., which would be about 25 per cent. In the Alleghany field of New York, recoveries have been obtained up to 12,000 bbl. per acre with a porosity estimated by Mr. Melcher of 21 per cent. That would be perhaps comparable to some of the higher recoveries secured by Dr. Uren, but there is apparently, in the application of these data to the field data, if our field data are correct, a discrepancy between the results obtained in the laboratory and the results we are getting. We are getting higher recoveries than indicated by the laboratory tests.

F. Fohs.—If these experiments had been undertaken on unconsolidated sands such as occur in the Gulf Coast, would the results be materially different?

J. B. Newby.—Yes, probably they would. On the other hand, the fact that the sand is tightly cemented can possibly mean that the pores are smaller than if the sands

* President, Goldelline Oil Corpn.

† Vice-president, Petroleum Reclamation Co.

‡ Vice-president, Humphreys Corpn.

were unconsolidated, and apparently with the smaller-sized grains in laboratory work smaller recoveries were obtained, so the discrepancy would still exist.

The Bradford sand is distinctly bedded, consisting of a number of layers, and in most places contains more or less slate. The gravity separation or the gravity concentration of oil in the lower part of the sand would, under such conditions, take place in individual layers. If it proceeded to any great extent, the upper part of the sand or the individual layer, as the case might be, might become quite lean. There would then be a marked differential between the resistance to flood movement in the upper and lower parts of the sand or layer. The water would tend to break through and by-pass the oil by moving ahead through the upper part of the sand. At Bradford there is not much opportunity for gravity separation. Perhaps that is the explanation of successful water-flooding in some sands which apparently are but little different from other sands where the process has been unsuccessful.

D. C. Barton,* Houston, Texas.—I am interested in the question of the amount of by-passing. Of course, I am out of my line a bit but it looks to me as if in a great many fields by-passing will waterlog the sand. I have been interested in the effect of repressuring sands with gas and it looks as if you are getting about as much improvement by repressuring, without water-logging the sand. With repressuring we may get 20 per cent. more oil out than we will with standard methods of production, and we would still leave the sand in good condition so the next generation may be able to pull out the next 20 per cent. There is a possibility of washing the sand with very wet gas, but with very great variation in porosity one would expect water-flooding would leave much of the sand inaccessible.

C. E. Beecher,† Bartlesville, Okla.—I was just about to ask Mr. Umpleby what his opinion is of the problem of dewatering the sand if at a later time it proved desirable to mine it or apply other methods of recovery.

J. B. Umpleby.—This question is important in water-flooding as undoubtedly much oil is left in the sand. My opinion is that any oil field of merit will go through three cycles; one of which will be normal methods of recovery; the next, special methods of recovery from the surface; and the third, actual mining. I was interested in the problem of mining to see what the pumping problem would be if it was later decided to mine a water-flood property. The cost of a pumping unit adequate to handle a thousand acre operation is remarkably small. The barrels of water per acre are so small compared with water that is lifted from mines, that the pumping problem is almost negligible. However, I think it is not negligible that much oil may be surrounded and isolated by water and cut off from the drainage tunnels of a mining system.

Of the methods for increasing the extraction of oil that are now being tried the one that I believe has the most merit is the maintenance of pressure from the start. Never let the energy run down. As it is lost at the front end of the tube it should be added at the back end. To take an old pool and repressure it, as we cannot apply agitation, requires time sufficient for diffusion to recharge the more or less isolated blebs of oil which is an infinitely slow process in the absence of the agitation. If by charging gas into the reservoir from the start, we can maintain the energy balance we are much better off, I believe, than by letting it run down and then hoping to recharge it.

C. V. Millikan,‡ Tulsa, Okla.—I notice that in these experiments it gives the length of the tubes as 16 in. long and 2½ in. in diameter, and his time on these is from

* Geophysical Research Corpn.

† Production Engineer, Empire Gas & Fuel Co.

‡ Petroleum Engineer, Amerada Petroleum Corpn.

two to eight days, which would give, I believe, a minimum movement of 2 in. per day to a maximum of 8 in. What was the movement found in the Bradford field?

F. M. Brewster,* Bradford, Pa.—The average movement there figured out about 80 per year. Those movements are variable because from one intake well the cubic contents of the sand increases with the square of the distance.

In connection with repressuring or recovering with air or gas, the Bradford field is about as good as any other field in the country for gas recovery. Recoveries increase between 400 to 600 per cent. by using air. The sand being very fine, it requires pressures better than 400 lb. to get any worth-while volume of air into the sand.

C. E. Beecher.—Is 400 lb. about the average pressure they have to use in the Bradford area generally or for that one particular property?

F. M. Brewster.—There are a few places where they have used down to 250 lb. One large company there has several compressors around 380 lb., but they are not getting satisfactory results. Our own company maintains a pressure of 420 lb.

* Petroleum Reclamation Co.

The Bradford Pool

In December, 1927, the Institute published two papers on the Bradford pool, which were presented at the New York meeting in 1928. Pamphlet copies may be obtained by writing to the Secretary's office for:

Oil-field Waters of the Bradford Pool, by Paul D. Torrey. *Technical Publication* No. 38.

Some Factors Influencing Production of Oil by Flooding in the Bradford and Allegany Fields, by Paul D. Torrey. *Technical Publication* No. 39.

Chapter VI. Sucker-rod Strains and Stresses

Sucker-rod Strains and Stresses

By F. W. Lake* and H. A. Brett,† Brea, Calif.

(New York Meeting, February, 1928)

With each year bringing the exploration of deeper and deeper producing horizons in the effort to maintain production, the problem of lifting the oil to the surface is continually becoming more difficult. Flowing and gas-lift wells eventually decline to such a point that pumping is necessary. The increasing loads on sucker rods resulting from deeper pumping operations are approaching the ultimate strength of the rods with consequent reduction in the factor of safety. With this diminishing factor of safety, the vibratory stresses causing fatigue, crystallization, and ultimate fracture become more important. These vibratory stresses are the result of varied pumping conditions which, if properly understood and investigated, may be eliminated to a great extent. To accomplish this purpose, a recording dynamometer has been developed which gives an indicator card showing the actual load on the polished rod at each point of the pumping cycle.

Recording Dynamometer

The instrument consists of a dynamometer head of the piston and cylinder type filled with castor oil, and a recording device, the movable card holder being connected with the dynamometer through a system of levers and the hollow spring gage connected with the fluid chamber of the dynamometer by a high-pressure flexible tube. The dynamometer head is hung from the beam with an ordinary hanger and lugs on the cylinder, while the piston is attached to the polished rod. The movable card holder actuated through levers moves in a vertical direction proportionate to the movement of the polished rod. The recording arm of the hollow spring gage inscribes on the card the pressure at all times. Thus by proper scales, the indicator card gives the load on the polished rod at all points in the pumping cycle. Fig. 1 shows the hookup of the recording dynamometer at a pumping well.

* Superintendent of Production, Union Oil Co. of California.
† Union Oil Co. of California.

The Pumping Cycle

In studying the motion of the polished rod during the pumping cycle three cases are developed. First, as Case I, the well is perfectly counterbalanced and the angular velocity of the crank is constant. Second, as Case II, the well is insufficiently counterbalanced and the angular velocity of the crank is decreasing on the upstroke and increasing on the downstroke of the polished rod. Third, as Case III, the well is excessively

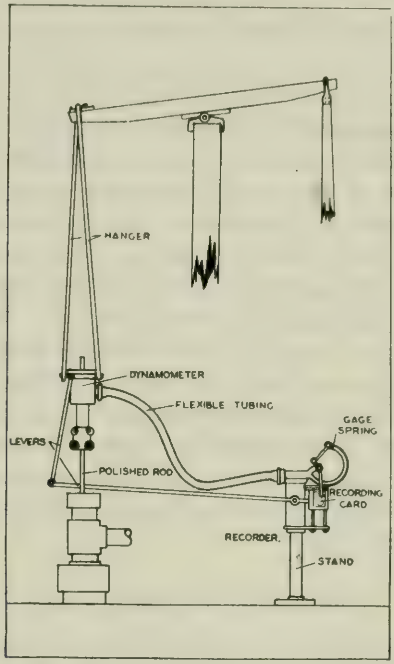


Fig. 1.—Arrangement of recording dynamometer installation.

counterbalanced and the angular velocity of the crank is increasing on the upstroke and decreasing on the downstroke of the polished rod. The motion in Case I approximates simple harmonic motion. Cases II and III are identified by similar analytical curves divergent in degree only. Fig. 2 illustrates the space-time, velocity-time, and acceleration-time curves of each case.

The Analytical Card

All possible curve slopes in each quadrant of the pumping cycle are shown in Fig. 3.

In quadrant I, polished-rod motion is characterized by an increasing positive velocity-time curve and a decreasing positive acceleration-time curve. Hence an increasing load as evidenced in the curve *ab* indicates

a greater polished-rod velocity than the plunger velocity. At the point *b* where the curve starts a straight vertical line, the velocities and accelerations of the polished rod and plunger are equal and remain equal throughout the straight line curve *bc*. The decreasing load evidenced in the

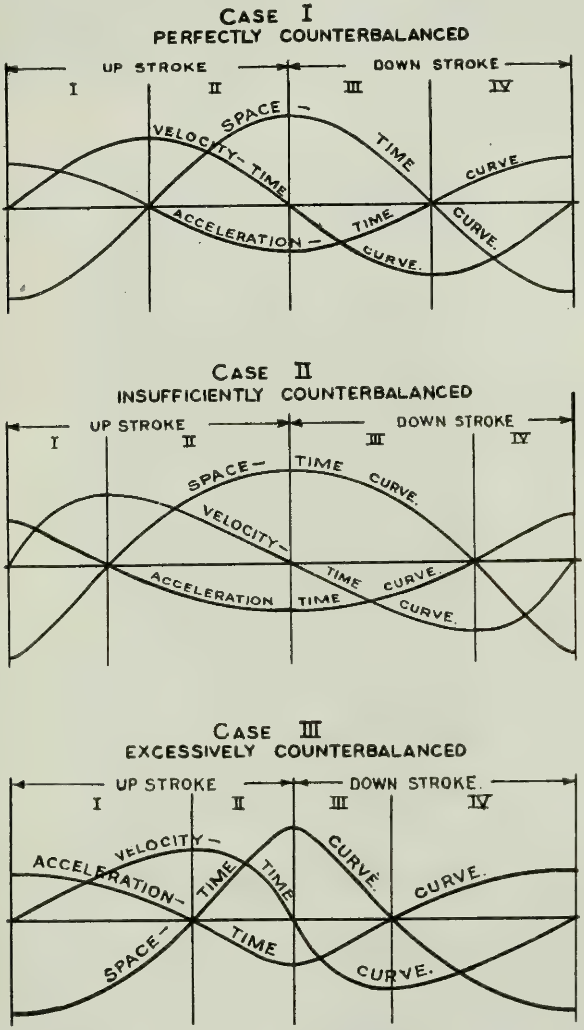


Fig. 2.—Motion curves of pumping cycle.

curve *cd* indicates a lower polished-rod velocity than the plunger velocity. Throughout the straight line *de*, the velocities and accelerations of the polished rod and plunger are again equal.

In quadrant II, polished-rod motion is characterized by a decreasing positive velocity-time curve and an increasing negative acceleration-

time curve. The constant load evidenced in the straight-line curve *ef* indicates equal velocities and accelerations of the polished rod and plunger. The increasing load indicated by the curve *fg* is occasioned by the polished-rod velocity again being greater than the plunger velocity. Throughout the straight-line curve *gh*, both the polished-rod and plunger velocities and accelerations are equal. The decreasing load indicated by the curve *hi* is due to the polished-rod velocity being less than the plugner velocity.

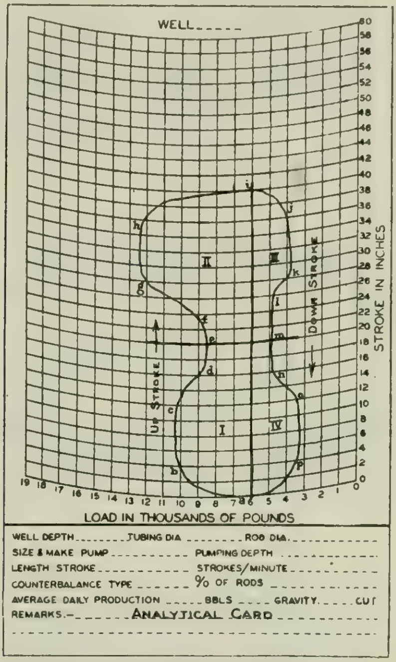


FIG. 3.—ANALYTICAL CARD.

In quadrant III, polished-rod motion is characterized by an increasing negative velocity-time curve and a decreasing negative acceleration-time curve. The decreasing load during the curve *ij* occurs as the polished-rod velocity is greater than the plunger velocity. In the constant load curve *jk*, both velocities and accelerations of the polished rod and plunger are equal. During the increasing load curve *kl*, the polished-rod velocity is lower than the plunger velocity. Throughout the straight-line curve *lm*, both velocities and accelerations are again equal.

In quadrant IV, polished-rod motion is characterized by a decreasing negative velocity-time curve and an increasing positive acceleration-time curve. The constant load curve *mn* indicates equal velocities and accelerations of the polished rod and plunger. The decreasing load

curve *no* is due to the polished-rod velocity being greater than the plunger velocity. The straight-line curve *op* is indicative of equal velocities and accelerations of the polished rod and plunger. The increasing load curve *pa* is caused by the polished-rod velocity being less than the plunger velocity.

A study of Fig. 2 in relation to Fig. 3 will give the motion curves for the plunger under the different sucker-rod load conditions.

The Ideal Card

Fig. 4 illustrates an ideal card both from a production and a sucker-rod load consideration. An analysis of this curve shows a smooth, rapid

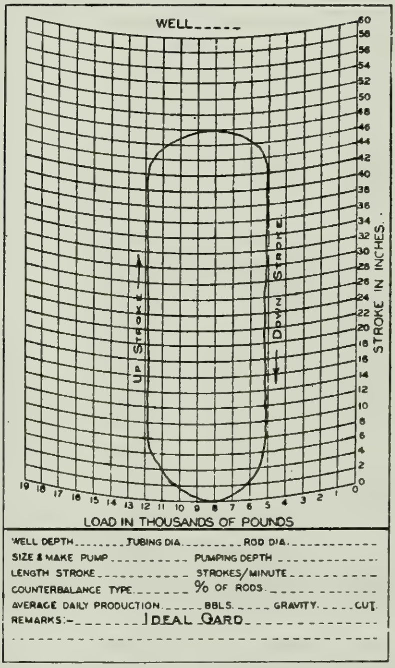


FIG. 4.—IDEAL CARD.

pickup, a continuous even load throughout the greater part of the upstroke, a gradual decrease in the load as the upstroke is completed and the downstroke started, a uniform minimum load throughout the greater part of the downstroke, and a smooth increase in load as the downstroke is completed. This card is the result of quick acting valves, free moving plunger, proper spacing, stroke, and speed to make optimum use of the relative velocity and acceleration cycles.

Counterbalancing Effect in Pumping with a Plunger Pump

Fig. 5a illustrates three comparative cards on a plunger pump with only the degree of counterbalancing changed. The point of load decrease

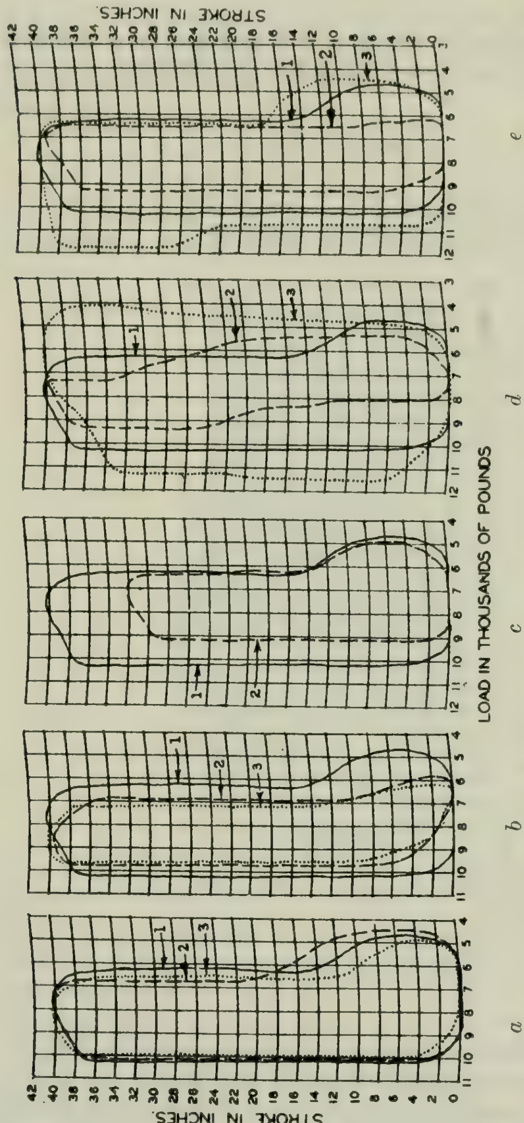


Fig. 5.—Comparative cards on a 2½-in. plunger pump.

a. Effect of various amounts of counterbalancing. Per cent. of rods: curve 1, 100; curve 2, 75; curve 3, 125.
b. Effect of various casinghead pressures: curve 1, 18 lb.; curve 2, 200 lb.; curve 3, 500 lb.
c. Effect of various lengths of stroke: curve 1, 40 in.; curve 2, 32 in.
d. Effect of number of strokes per minute: curve 1, 23; curve 2, 18; curve 3, 30.
e. Effect of various pumping depths: curve 1, 4232 ft.; curve 2, 3982 ft.; curve 3, 4447 ft.

Well depth = 4577 ft.; tubing diam. = 2½ in.; rod diam. = ¾ in.; pumping depth = 4232 ft. except for card *e*; length of stroke = 40 in. except for card *c*; strokes per minute = 23 except for card *d*; per cent. of rods = 100 except for card *a*. Counterbalance type = band wheel. Average daily production: *a* = 155 bbl.; *b* = 142 bbl.; *c* = 117 bbl.; *d* = 155 bbl.; *e* = 190 bbl. Gravity: *a* = 16.3; 48.7 cut; *b* = 16.3; 47.8 cut; *c* = 16.5; 48.2 cut; *d* = 16.3; 48.7 cut; *e* = 16.4; 50.1 cut.

in the fourth quadrant is the major difference and results indicate that with the heavier counterbalance the polished-rod velocity becomes greater than the plunger velocity nearer the end of the downstroke.

Casinghead-pressure Effect in Pumping with a Plunger Pump

Fig. 5*b* illustrates three comparative cards on a plunger pump with only the amount of casinghead pressure varied. This series of cards indicates several effects of casinghead pressure. Increased casinghead pressure results in (1) a more gradual pickup, (2) a lower maximum load, (3) a more rapid decrease in load at the end of the upstroke, (4) a greater load throughout the downstroke, (5) a less pronounced decrease in load toward the end of the downstroke, and (6) no increase in load at the end of the downstroke.

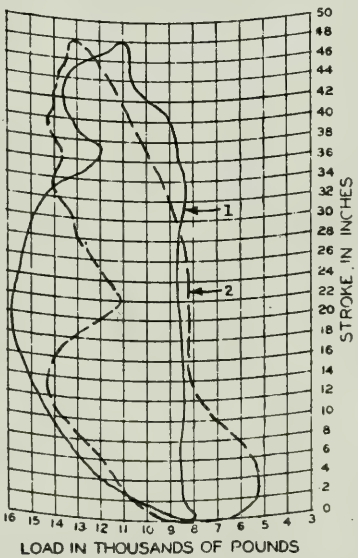


Fig. 6.—Effect of excessive vibration on the upstroke of a 3-in. plunger pump.

Well depth = 4627 ft.; tubing diam. = 3 in.; rod diam. = ¾ in.; pumping depth = 4314 ft.; length of stroke = 48 in.; strokes per minute: curve 1, 35; curve 2, 18. Counterbalance type = band wheel. Per cent. of rods = 100. Average daily production, 150 bbl.; gravity, 22.0; 7.2 cut.

Effect of Length of Stroke with a Plunger Pump

Fig. 5*c* illustrates two comparative cards on a plunger pump, the only difference being in the length of the stroke. The similarity between these cards is self-evident.

Effect of Pumping Rate with a Plunger Pump

Fig. 5*d* illustrates three comparative cards on a plunger pump, the only difference being in the number of strokes per minute. The major features with increasing speed are (1) the increasing width of the diagrams and (2) the more uniformity in load.

Effect of Different Pumping Depths with a Plunger Pump

Fig. 5e illustrates three comparative cards on a plunger pump, the only difference being in the depth of the working barrel. From the diagrams, it is evident that increased pumping depths result in (1) greater maximum loads, (2) the development of a secondary pickup in the second quadrant, and (3) the polished-rod velocity becoming greater than the plunger velocity earlier in the fourth quadrant.

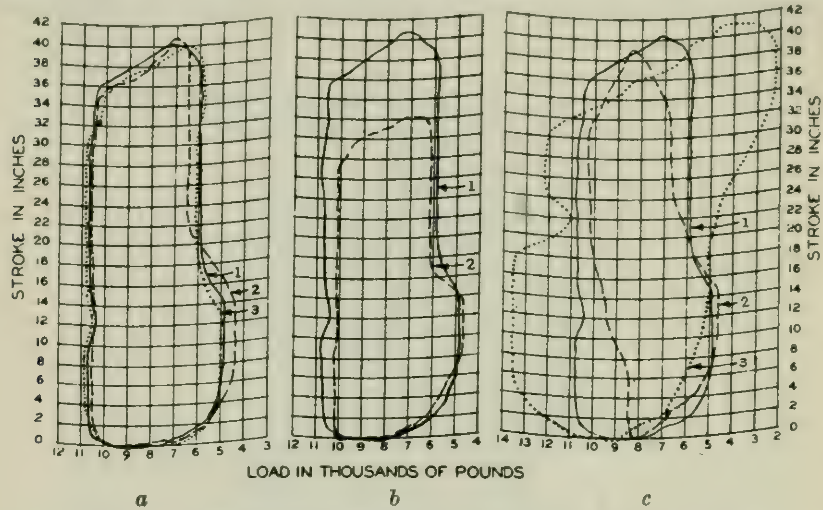


Fig. 7.—Comparative cards on a 2½-in. fluid-packed pump.

a. Effect of various counterbalancing. Per cent. of rods: curve 1 = 100; curve 2 = 75; curve 3 = 125.
b. Effect of different lengths of stroke: curve 1 = 40 in.; curve 2 = 32 in.
c. Effect of number of strokes per minute: curve 1 = 23; curve 2 = 18; curve 3 = 33.
Well depth = 4577 ft.; tubing diam. = 2½ in.; rod diam. = ¾ in.; pumping depth = 4222 ft.; length of stroke = 40 in. except for card *b*; strokes per minute = 23 except for card *c*; per cent. of rods = 100 except for card *a*. Counterbalance type = band wheel. Average daily production: *a* = 187 bbl.; *b* and *c* = 188 bbl. Gravity: *a* = 16.1; *b* and *c* = 16.4. 48.1 cut.

Excessive Rod Vibration

The excessive vibration which can occur even at relatively slow pumping speeds is indicated in Fig. 6. In this case, almost doubling the number of strokes per minute greatly reduces the rod vibration and fatigue with but a slight increase in load.

Counterbalancing Effect with a Fluid-packed Pump

Fig. 7*a* illustrates three comparative cards on a loose fitting fluid-packed pump with only the degree of counterbalancing changed. The same effect of counterbalancing is shown as is illustrated in Fig. 5*a* with a plunger pump.

Effect of Length of Stroke with a Fluid-packed Pump

In Fig. 7*b* two comparative cards are shown on a fluid-packed pump, the only difference being in the length of the stroke. The similarity between these cards is self-evident.

Effect of Pumping Rate with a Fluid-packed Pump

Fig. 7*c* illustrates three comparative cards on a fluid-packed pump, the only difference being in the number of strokes per minute. The major

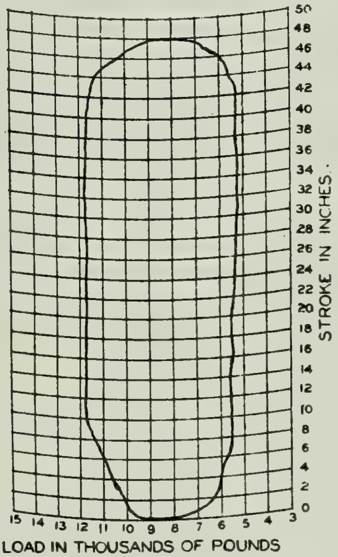


Fig. 8.—Nearly perfect chart of 2½-in. fluid-packed pump.

Well depth = 4690 ft.; tubing diam. = 2½ in.; rod diam. = ¾ in.; pumping depth = 4543 ft.; length of stroke = 48 in.; strokes per minute = 28; per cent. of rods = 100. Counterbalance type = band wheel. Average daily production = 80 bbl.; gravity = 14.5; 67.2 cut.

features with increased speed are (1) the increasing width of the diagrams and (2) at high speed the increasing load throughout the downstroke.

Fig. 18 illustrates a card which approaches the ideal card shown in Fig. 4.

Counterbalancing Effect in Pumping with a Cup Pump

Fig. 9*a* illustrates our comparative cards on a cup pump, only the degree of counterbalancing being varied. The point of load decrease in the fourth quadrant is the major difference and results indicate that with the heavier counterbalance the polished-rod velocity becomes greater than the plunger velocity nearer the end of the downstroke up to and including 100 per cent. rod counterbalance. This is similar to Figs. 5*a*

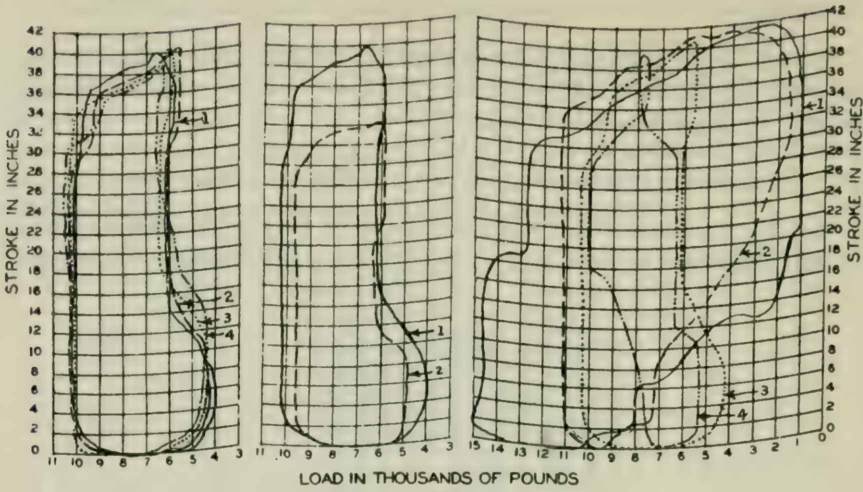


FIG. 9.—COMPARATIVE CARDS ON A $2\frac{1}{2}$-IN. CUP PUMP.

a. Effect of various counterbalancing. Per cent. of rods: curve 1 = 100; curve 2 = 75; curve 3 = 125; curve 4 = 0.

b. Effect of different lengths of stroke: curve 1 = 40 in.; curve 2 = 32 in.

c. Effect of number of strokes per minute: curve 1 = 36; curve 2 = 33; curve 3 = 23; curve 4 = 18.

Well depth = 4577 ft.; tubing diam. = $2\frac{1}{2}$ in.; rod diam. = $\frac{3}{4}$ in.; pumping depth = 4220 ft.; length of stroke = 40 in. except for card *b*; strokes per minute = 23 except for card *c*; per cent. of rods = *a* (see above); *b*, 100; *c*, 75. Average daily production: *a* = 156 bbl.; *b* and *c* = 164 bbl. Gravity = 16.3. *a*, 47.2 cut; *b* and *c* 48.8 cut.

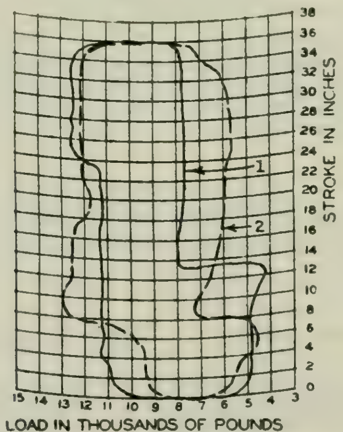


FIG. 10.—EFFECT OF $2\frac{1}{2}$-IN. CUP PUMP STICKING ON DOWNSTROKE.

Well depth = 4750 ft.; tubing diam. = $2\frac{1}{2}$ in.; rod diam. = $\frac{3}{4}$ in.; pumping depth = 4440 ft.; length of stroke = 36 in.; strokes per minute: curve 1 = 28; curve 2 = 32; per cent. of rods = 75; counterbance type = band wheel. Average daily production = 200 bbl.; gravity = 20.8; 30.2 cut.

and 7*a* for the other types of pumps. However, at 125 per cent. rod counterbalance, this point of load decrease takes place earlier in the downstroke which is at variance with the results obtained with the other types of pumps.

Effect of Length of Stroke with a Cup Pump

Fig. 9*b* illustrates two comparative cards on a cup pump, the only variable being the length of stroke. As in Figs. 5*c* and 7*b*, the similarity between the diagrams is self-evident.

Effect of Pumping Rate with a Cup Pump

Fig. 9*c* illustrates four comparative cards on a cup pump, the only difference being in the number of strokes per minute. The major features with increasing speed are (1) the increasing width of the diagrams and (2) the increasing load throughout the downstroke at high speeds. This is similar to the results with the other types of pumps as illustrated in Figs. 5*d* and 7*c* with one exception. At the slow speed, the load decreases at the end of the upstroke and increases at the beginning of the downstroke.

Excessive rod vibration on the downstroke caused by the plunger sticking in the barrel is shown in Fig. 10.

Summary

The cards illustrated indicate a wide variance in pumping loads. These divergent pumping conditions are not only due to the peculiarities of individual wells, but also are the result of the pumping equipment used and the method of operation. If proper attention is paid to all factors that enter into and affect the pumping cycle, rod vibration, which is the primary cause of rod failure, may be reduced to a minimum, thereby increasing the life of the rods and production efficiency.

DISCUSSION

F. J. Fohs,* New York, N. Y.—Would the results have been different with high-gravity crude?

C. V. Millikan,† Tulsa, Okla.—I believe the effects would be essentially the same. I do not consider, however, that the value of this paper lies so much in the specific curves shown as in the method of obtaining and analyzing sucker-rod strains and stresses. I am sure, if we use this method on other wells, that we will be surprised at the variation in conditions shown by the curves even where, to all appearances, conditions are identical. It is not the author's intention that conclusions drawn from a study of these curves can be applied to pumping wells in general but rather that this method will give a quantitative analysis of one part of the problem of pumping efficiency.

* Vice-president, Humphreys Corpn.

† Petroleum Engineer, Amerada Petroleum Corpn.

F. W. LAKE.—The curves shown are not meant to be applied directly as showing the variance in loads under all conditions. The curves merely show on one well what differences can be expected with different operating conditions. On another well, different operating conditions will undoubtedly result in different curves which would be entirely dissimilar to the curves illustrating the paper.

C. E. BEECHER,* Bartlesville, Okla.—The authors deserve credit for the method they employed to obtain data on sucker-rod strains and stresses; it is worthy of further consideration. About two years ago we designed such an apparatus to determine the actual horsepower delivered to the polished rod under varying conditions and later used it on shackle rod lines. Our experiences indicate that the recording dynamometer is an excellent instrument with which to obtain data but care must be used when interpreting the results.

J. B. UMPLEBY,† Oklahoma City, Okla.—The Marland Oil Co. of Texas has been using a dynamometer which records the angular position of the pumpjack and the load at the same time. A few companies in Oklahoma are working along the same line, all indicating the recognition of a need to reduce pumping to a science. It is an additional recognition of engineering methods by the oil industry.

One thing Professor Lake did not bring out in his paper is that sucker-rod guides greatly reduce the loan, as indicated on dynamometer charts. I understand that in California they are using rather extensively some kind of a bronze guide which greatly reduces friction and the wear on tubing. The guides are attached to the rods and travel with them.

F. W. LAKE.—We made no tests with the dynamometer in connection with sucker-rod guides.

F. M. BREWSTER,‡ Bradford, Pa.—At Bradford 1800 ft. of ⅝-in. iron rods gave a 3-kw. load, whereas 500 ft. of iron rods and 1300 ft. of wooden rods gave a 2-kw. load.

J. B. UMPLEBY.—That exceeded their difference in weight, did it not?

F. M. BREWSTER.—Yes. It seems to indicate much less friction with wood than with iron rods.

Referring to Fig. 3, it looked to me that at the upper part of the curve the load immediately jumps up; that the first, say, five-eighths of that load was due to the rods, and the plunger had not even moved; and the last part is where the load jumps up, where the plunger is starting to move. In other words, if you had a ⅜-in. stroke, with 18 or 20 in. of rod only, the final movement of the plunger might be anywhere from 12 to 18 in. I wonder if the paper states just what movement they got at the plunger as compared with the surface?

F. W. LAKE.—Fig. 3 is an analytical card and was not taken from any well. It was merely used to illustrate all possible curve angles that could be obtained on an indicator card.

In reference to plunger movement, this is readily worked out by obtaining actual space-time, velocity-time, and acceleration-time curves from the polished rod and applying to these curves the rate of increasing load as shown on the indicator card and thus obtaining space-time, velocity-time, and acceleration-time curves of the plunger.

---

* Production Engineer, Empire Gas & Fuel Co.

† President, Goldelline Oil Corpn.

‡ Petroleum Reclamation Co.

C. V. Millikan.—The paper mentions the velocity of the polished rod as related to that of the plunger but it does not discuss the relationship.

F. M. Brewster.—As the depth increased, the power and load increased on the upper part of the curve, which also indicated to me there was no movement of the plunger previous to that time.

Fig. 6 shows better cards for faster strokes as far as the rods are concerned, but with the slower stroke, using the same argument as I had on the plunger, it would probably give more efficient pumping. They are sacrificing the rods by pumping on low, slow strokes, but saving the rods at the expense of production on the faster strokes. It is interesting that all the cards show an excessive load. It is brought out that the counterbalancing had no material effect on this except as a saving in power consumption.

F. W. Lake.—The production was increased 10 per cent. on the faster stroke, thus giving more production and less rod fatigue at the faster stroke.

C. V. Millikan.—The paper deals entirely with the effect on the rod. Any other effect it may have is not discussed.

D. C. Barton,* Houston, Texas.—As taken from these indicator cards, the counterbalancing did have an effect.

C. V. Millikan.—Some time ago we tried counterbalancing using a watt meter as an indicator. We got some perfect counterbalancing as far as power was concerned but the effect on the rods was disastrous.

F. J. Fohs.—Does not the relationship of power consumption to these effects warrant further research?

C. V. Millikan.—Yes.

---

* Geophysical Research Corpn.

Chapter VII. Deep-well Drilling Technique

Deep-well Drilling Technique

By H. H. Dievendorff* and F. W. Hertel,* Ventura, Calif.

(New York Meeting, February, 1928)

The method of drilling deep wells into the earth for the recovery of oil and gas is beset with many hazards. This is especially true in the Ventura Avenue field, which has the distinction of being the hardest field in California in which to complete a deep well. The hard, shifting and squeezing formations must be penetrated to great depths in the face of tremendous gas pressures. This field presents problems that keep the operators abreast with all of the latest developments in oil-field tools and machinery and in oil-well drilling practices. Equipment must be strong, and adapted to deep-well drilling and the handling of long heavy strings of casing. High-pressure sands require the utmost care and attention of the operators and no chances can be taken, since a serious blowout may cause the loss of a well that has cost months of labor and expense. Equipment must meet these requirements or be discarded.

Although the deepest wells in the world are not in this field, nor have the longest strings of casing been set, nevertheless, the consistency with which deep wells are drilled and long strings of casing are set places the Ventura Avenue field foremost, in this respect, among the oil fields of the world. The Ventura Avenue field does claim the deepest commercial oil-producing well in the world, in the Shell Co. of California's "Edison" No. 18. This well was drilled 7015 ft. and came in flowing 3280 bbl. of oil per day. This field also claims the deepest average depth of producing wells in that its 111 producing wells average 5676 ft. in depth. Of these 111 producing wells, 50 are 6000 ft. or deeper, and 16 are 6500 ft. or deeper. Also, of the 111 producing wells 100 are flowing, and 11 are pumping wells.

This paper is intended to set forth the methods used in the drilling of deep wells with rotary tools and the handling of long heavy strings of casing in the Ventura Avenue field.

Surface Equipment

Practically all rigs in the Ventura Avenue field are 122-ft. standard heavy galvanized steel derricks with a 24-ft. base. A cellar is dug

* Field department, Union Oil Co. of California.

about 20 ft. below the derrick floor. This depth of cellar allows for all the casing connections that are necessary to drill the deep holes. Each derrick leg is reinforced with heavy pipe resting securely on the corner foundations, which increases the safe load almost three times. Two of these heavy pipe reinforcements act as standpipes. Each rig has two mud hoses, each attached to a standpipe. The hoses are 2½-in. diam., wound with round galvanized wire and tested to 2000 lb. per sq. in.

The pump house is on the side of the rig that has the standpipes. The floor of the pump house is almost 3 ft. lower than the floor of the derrick, thus insuring a minimum lift of the mud fluid from the slush pit. The pump house is equipped with two large mud pumps (14 by 7¼ by 14 in.) with 8-in. suctions and 3-in. discharge lines. These pumps are connected so that each pump can work independently or may be "compounded." By "compounding" these pumps and reducing the size of the pump liners, a pressure of over 2000 lb. can be built up. Long settling ditches are built to drop the sand out of the mud. The slush pit is divided into two sections. The ditch dumps into one side and the mud flows over the top of the partition into the adjoining side and is picked up by the slush pumps. This keeps a large amount of sand from remaining in the mud that is being circulated.

The rotary engine commonly used is the 12 by 12-in. twin-cylinder steam engine. This large size insures greater power and more flexibility in handling heavy loads. The engine has a splash-feed lubrication for the main bearings, crank pins, connecting-rod bearings and crossheads, and a force-feed lubrication for the cylinders. The rotary engine is supplemented by a single-cylinder 12 by 12-in. steam engine which operates the calf wheel, band wheel and sand reel.

The rotary draw works commonly used is the three-speed, extra heavy type designed for heavy duty. The two types in use have 6½ or 7½-in. drum shafts, and 5⅞ or 7-in. line shafts. The 6½-in. drum shaft has three supports, and the 7½-in. drum shaft has two supports which are roller bearing. Both types of line shafts have the three supports and have plain babbitt bearings. The drums are press-forged steel. Most draw works have the automatic cat-head equipment, brake equalizer and a line spooler. The rotaries are the chain-driven, roller-bearing type with 25½ or 27½-in. opening through the table.

The rotary swivels are the extra heavy all steel roller-bearing type designed for heavy duty. The swivel bail is 3 to 4-in. diam. and equipped with safety chains attached to the mud hose.

The double extra heavy elevators are used with 2½ or 3-in. by 6-ft. links.

The 8-in. wiggle spring hook with the automatic safety latch is used.

Traveling blocks are the four or five-sheave type equipped with roller bearings. The sheaves are made of manganese steel and are usually 30 to 36-in. diam. The traveling block carries guards on the

outside, the newer types being leather faced to prevent wear on the drilling line.

Because of the heavy load that the derrick must support, and consequently the crown block, new designs of crown blocks have come into use. The basic principle of these crown blocks is to have the sheaves in line with the sheaves of the traveling block, either the same diameter as the traveling block sheaves or larger, and to be of the roller-bearing, manganese-steel type. The larger roller-bearing sheaves prolong the life of the wire line and insure speed of operation. The new design allows the traveling block to be elevated higher in the derrick than the old style crown block where the sharp angle of the wire line (spread) limits the height to which the traveling block can be raised.

The drilling lines are 1-in. wire lines and are either 2000 or 2500 ft. long. The long line is preferred because it is easier to cut off the worn line at the drum, where most of the wear occurs, and spool off new line from the calf wheel, where the reserve is carried, than to replace with a new drilling line. The "dead line" is attached to the calf wheel so that in case the draw works or rotary engine breaks down the drill pipe can be moved by the standard engine to keep it from "freezing" while repairs are being made. It is good practice to have the standard engine turning over slowly while drilling so the pipe can be moved immediately if necessary. The drill pipe has "frozen" in the Ventura Avenue field when a breakdown of a few minutes' duration has occurred while the pipe was on bottom.

A weight indicator is fastened to the "dead line" just above the calf wheel and the recorded weight is shown on an indicator dial, which is placed in a position easily seen by the driller. In drilling at great depths, running long strings of casing, or in fishing for lost tools, the weight indicator shows a relative change in weight much more accurately than the driller can ascertain by standard rotary equipment.

On account of the abundance of gas in the field, the power plants consist of 70 to 80-hp. firebox or tubular boilers with a working pressure of 125 to 175 lb. The usual program is three boilers per rig.

Because of the sandy nature of the formations in the Ventura Avenue field, the wells do not make mud while drilling; consequently each lease has a central mud-mixing plant. Great quantities of mud are used in the drilling of the wells in the Ventura Avenue field, and in cases of emergency, such as wells attempting to blow out, the mud must be shipped to the well in trouble in large, consistent amounts.

The mud-mixing plant has a large paddle mixer that takes the dry clay, which is hauled from a pit approximately a mile distant, and mixes it into mud fluid weighing 76 to 82 lb. per cu. ft. Steam pumps pick up the mud from large sump holes or large tanks, and pump it to the wells, each well being connected to the mud-mixing plant. Each rig has a return

pipe line to the mud-mixing plant so gas-cut mud can be reconditioned. When the wells are drilling into the high-pressure oil and gas sands, a tank of surplus mud is kept at each rig.

Casing Program

The next consideration in the drilling of deep wells is the choosing of a casing program that will meet with water shut-off requirements of the particular field in which the wells are to be drilled and will also keep the hole large enough to allow the well to be drilled to a great depth.

This program must also take into consideration the fact that long strings of casing are sometimes stuck before the proper water shut-off point is reached and it may become necessary to land a smaller casing. If the original string is already small, the hole becomes "pointed" and deeper drilling is very much limited.

The casing program in the Ventura Avenue field has gradually gone through a process of evolution as commercially productive sands have been found at greater depths, until, at present, the majority of the wells are being drilled with the intention of attaining a depth of at least 6500 ft. The usual practice calls for a string of 18⅝ or 20-in. stovepipe or screw casing to be cemented at a depth of approximately 650 to 750 ft. This depth is absolutely necessary to case off the running sands and gravels and to make certain that when the surface string is cemented a gas blowout will not occur on the outside of all casings.

Next a string of 11¾ or 13⅜-in. A. P. I. seamless casing is set at a depth of 3000 to 4400 ft., depending on the elevation of the wall and its position on the structure, for the primary water shut-off. This primary water string shuts off a large volume of the water. In reality, it serves as a second surface string; otherwise the amount of casing necessary to effect the permanent water shut-off would have too much friction and would "freeze" before reaching the required depth.

The secondary shut-off is made with either 10¾, 9, or 8⅝-in. A. P. I. seamless casing, depending on whether 13⅜ or 11¾-in. A. P. I. casing was used for a primary shut-off, and the depth to which it must be carried. The secondary shut-off is made at depths varying from 700 to 1800 ft. below the primary shut-off. On account of edge-water encroachment in the upper sands, it is necessary to set the secondary water strings on the flanks of the structure considerably lower than in the center field; therefore, in some of the wells now being drilled, it will be necessary to land secondary water strings with over 2000 ft. of friction, which will necessitate landing 9 or 8⅝-in. A. P. I. casing consistently at depths of over 6000 feet.

The wells are then completed with either 6⅝ or 5¾-in. A. P. I. oil string, the secondary water shut-off generally being reinforced by a combination water shut-off with the oil string. Oil strings with over 2500

ft. of perforated pipe have been successfully landed and clean wells brought in. Wells in which the extent of the oil-bearing zone has not been determined (edge wells) are often brought in with open hole below the secondary water string. This is made possible in the Ventura Avenue field on account of the hardness of the oil formations, which allow the wells of the open hole to stand up. In case the wells come in wet, the source of the water entering the hole can be determined and the water shut off. This method will also allow the wells to be later deepened without decreasing the diameter of the hole.

As previously mentioned, water strings are sometimes stuck before the proper cementing place is reached, which necessitates the use of a smaller string of casing at the intended depth. This generally makes it necessary to use 6⅝-in. casing for the secondary water string, and necessitates the use of 4¾ or 3-in. A. P. I. oil string, or bringing in the well in open hole.

The depths at which casings of various sizes have been landed successfully in the Ventura Avenue field are given in Table 1, as several are probably of world-record caliber.

Table 1.—*Depths at Which Casings Have Been Landed at Ventura Avenue Field*

Size, Inches A. P. I.	Weight, per Ft.-lb.	Depth, Feet	Total Weight, Tons	Company	Well
13⅜	61	4321	131.8	Shell	Gosnell No. 25
11¾	54	4359	117.7	Pet. Sec.	Orten No. 5
10¾[a]	45	3930	88.4	Assoc. Oil	Lloyd No. 43
9	45	5675	127.7	Assoc. Oil	Dabney-Lloyd No. 1
8⅝	36	6055	109.0	Pet. Sec.	Willett No. 3
6⅝	26	6790	88.0	Assoc. Oil	Lloyd No. 38
5¾	20	6997	70.0	Shell	Edison No. 18

[a] The 10¾-in. A. P. I. casing is not a popular string in the Ventura Avenue field and is usually based only on short secondary water strings.

Drilling Equipment

The drill pipe should be capable of making sufficient hole to set the casing at the required depth. A square "kelley" (drill stem) about 50 ft. long is desirable because it allows the driller to use the drill pipe in "doubles" rather than "singles." The "kelley" is equipped with a stopcock so that in case the mud hose blows up the stopcock can be closed until a new mud hose is connected. This will prevent the well coming in out of control through the drill pipe.

A long drill collar (approximately 30 ft.) is used on all sizes of drill pipe. This gives additional weight above the bit, and since the twistoffs usually occur just above the drill collar, it is easier to fish out.

All fishtail, disk bits and core barrels are faced with hard metal, which lessens the running of the drill pipe in and out of the hole. The hard and sandy formations soon take the cutting edge off the regulation steel bits.

Kammerdiner jars, to fit all sizes of drill pipe, are run on all fishing tools, just below the drill collar. In case the "fish" has become stuck in the hole it will then be possible to jar with the drill pipe and loosen. A safety joint is used in conjunction with the Kammerdiner jars so that in case the "fish" cannot be loosened it will be possible to back off the drill pipe at the safety joint and thus leave a minimum amount of additional tools in the hole. The Kammerdiner jars are also used while underreaming and sometimes while coring, so that if the underreamer or core barrel become stuck, they may be jarred loose.

The drilling lines are strung through the sheaves of the crown block and the sheaves of the traveling block three times. In other words, drilling is done with six lines. In case the load becomes very heavy, eight lines are strung.

Eight-inch (8⅝-in. A. P. I.) 45-lb. or 6-in. (6⅝-in. A. P. I.) 25.2 lb. seamless upset drill pipe is used in making the hole for the 18⅝-in. A. P. I. casing, or the 20-in. stovepipe casing.

Six-inch (6⅝-in. A. P. I.) 25.2-lb. seamless upset drill pipe is used in making the hole below the surface casing, to the required depth for the primary water string.

Five-inch (5$\frac{9}{16}$-in. A. P. I.) 22.2-lb. seamless upset drill pipe is used in making the hole for the secondary water shut-off. The greatest depth to which 5-in. drill pipe has been used is 5886 ft. In case it is necessary to drill below this point to set the secondary water string, 4-in. drill pipe is used.

Four-inch (4½-in. A. P. I.) 16.6-lb. seamless upset drill pipe is used in making the hole through 10¾, 9, or 8⅝-in. casing into the oil zone.

In case 6⅝-in. casing has been used for a water string, 3 in. (3½-in. A. P. I.) 12.3-lb. seamless upset drill pipe is used in drilling through it into the oil zone.

Tool joints are used with every two joints of drill pipe, on all sizes, so that the drill pipe may be handled in doubles.

Drilling and Setting Casing

The drilling of oil wells in the Ventura Avenue field requires the utmost care. In spudding in a well, great care must be taken to start the hole straight. The reason for this is obvious when the great finishing depth is considered. The hole must be kept straight until the surface casing has been cemented. A 28 or 29-in. stovepipe casing is set about 4 ft. below the bottom of the cellar to act as a conductor of mud fluid while drilling.

The wells are spudded in with 25 or 27-in. fishtail bits. The "kelley" is guyed in four directions to insure straightness of hole at the surface. The 25 or 27-in. hole is drilled to a depth of 650 to 750 ft., using fishtail or disk bits. A Wiggins straight reamer is usually run above the bit or just above the drill collar, which tends to center the bit in the hole and keep the hole straight. It also keeps the hole to gage and eliminates the necessity of reaming before the surface casing is run.

The wells in the bed of the Ventura River are spudded in with cable tools. The large boulders in the stream channel make it almost impossible to drill a straight hole with rotary tools. It is necessary to drill about 50 ft. with cable tools to get past the gravel and boulders, but once past this depth, rotary tools are installed. The cable-tool hole is cased with 29-in. stovepipe casing with a steel drive shoe on bottom. The casing is driven down while the cable-tool hole is being made, the casing being kept about 3 ft. behind the bit.

The 18⅝ or 20-in. casing is now run in the 25 or 27-in. rotary hole. The casing is run through a spider set on top of the rotary table. The bottom of the surface casing is equipped with a steel casing shoe and a cast-iron guide. The casing is left about one foot off bottom to insure its hanging straight in the hole and is then cemented. Sufficient cement is used to fill the space between the walls of the hole and the casing the entire distance to the surface. In case the cement does not reach the surface, cement is pumped in from the surface through 2-in. line pipe to fill the remaining distance. The cement is allowed to set from two to four days. On account of the cavities encountered in the upper strata, over 2000 sacks of cement are often used in cementing the surface casing.

The reason for cementing the casing the entire distance to the surface is that in case of drilling into a gas sand before setting another string of casing, the well will not be allowed to blow out on the outside of the conductor casing, with the consequent loss of the hole. It is often necessary to drill through this casing as long as four months before reaching the required depth to set the primary water string. In case the surface casing becomes worn out, the cement around the outside will prevent it from collapsing.

The conductor casing is now cut off at the bottom of the cellar. The surface casing, which has just been cemented, is then cut off about one foot above the cellar floor and a bottom flange is welded on. A short piece of casing (the same size that has been used as surface casing) is now used for the conductor pipe. This conductor pipe has a companion flange welded on the bottom and a blowout preventer welded on top with a 6-in. mud-outlet pipe welded into it just below the blowout preventer. The companion flange is bolted to the bottom flange and the 6-in. mud-outlet line is connected to the settling ditch by means of a flange union. The blowout preventer consists of a steel body, rubber packing assembly that will fit either drill pipe or kelley, and a screw lip ring. The drill pipe

is packed off by placing a split packing assembly around it and screwing down the lip ring.

The mud-discharge line is connected to the conductor pipe by a flange union, and is equipped with a high-pressure valve which allows the mud discharge to be run through the mud-settling ditch, or through an outside flow assembly. In case the well attempts to blow out, the combination of a blowout preventer around the drill pipe, together with the outside flow assembly, restricts the mud from being discharged from the hole faster than new mud can be pumped down to kill the gas.

After cementing the surface casing and equipping the rig for possible blowouts, the drilling is continued. A 17–14 or 19-in. rotary hole is drilled with 6-in. (6⅝-in. A. P. I.) 25.2-lb. drill pipe using disk bits almost entirely, although fishtail bits are occasionally used. A 17¼-in. rotary hole is drilled if 11¾-in. casing is to be used as a primary water string and a 19-in. hole is drilled when 13⅜-in. casing is to serve as the primary water string. The hole is reamed about every 500 ft. to keep a full gage hole. It will be seen, therefore, that it is necessary to set 20-in. surface casing if 13⅜-in. casing is to be used for the primary water string. This is done to insure the overshot going to bottom in case of a fishing job.

Particular attention is given to the mud when drilling a hole of this size. If too much sand remains in the mud after running through the settling ditches and settling box, the mud is discarded and new mud is supplied. Sandy mud will not "wall up" the drill hole. Also, in case of the drill pipe parting, the sand will drop out of the mud and settle around the tool joints and collars of the pipe remaining in the hole and cause it to "stick." The mud should weigh from 76 to 82 lb. per cu. ft.; mud heavier than this retards drilling and lighter mud will cause the walls of the drill hole to cave.

The hole is drilled and reamed to the depth required for the primary water shut-off. The hole is then conditioned for running casing. This consists of discarding all the drilling mud and replacing it with new mud weighing about 78 lb. per cu. ft.

Just before making the last run to bottom with the drill pipe, a new line is spooled on the drum and 10 lines strung through the crown block and traveling block with the "dead line" attached to the calf wheel. The casing can thus be moved by means of the standard engine in case the rotary engine or draw works break down. The stringing of the lines at this time avoids too much time out of the drill hole before running casing, so the mud will still be in good condition.

The drill pipe is removed from the hole and the rotary table set to one side. Two 16 by 16-in. timbers are placed crossways to the derrick sills and the casing spider is set on top. These 16 by 16-in. timbers usually have a ⅜-in. plate of boiler steel on top to prevent the ears of the spider from digging into the wood.

The drilling hook is replaced by a 9-in. wiggle hook and the double extra heavy casing elevator is hung on the hook by 3-in. by 6-ft elevator links.

The casing has a steel shoe equipped with a float valve on the bottom and usually a steel collar equipped with a float valve on top of the shoe joint or on top of the second joint from bottom. This float collar is an additional insurance in case the float valve on the casing shoe is broken while running the casing down the hole. The float guide on bottom allows continual circulation on the outside of the casing while running it in the hole.

The casing is first screwed together by hand with two sets of chain tongs and finished by the casing tongs. The tongs are operated by a jerk line from the crank off the band wheel, which in turn is run by the standard engine. All casing collars are tightened by hand with heavy chain tongs before pulling the joints of casing into the rig.

The casing is run to the bottom of the surface string (650 to 750 ft.), the circulating head is placed in the top of the casing and mud is circulated to ascertain if the float valves are operating. At this time a smaller (12-tooth) sprocket replaces the ordinary 18-tooth drilling sprocket on the rotary engine.

The casing is now run to within 300 to 600 ft. from bottom, where the float valves are again tested by the circulation of mud. The casing is filled with mud at frequent intervals, while running the casing in the hole, so as not to allow more than 300 to 600 ft. of casing to remain empty at any time. The slip elevator now replaces the regular elevator. This type of elevator removes all weight from the top collar, which might be spread if excessive weight were suspended on the collar, and also prevents the threads from stripping. In case slip elevators are not used, the top collar is protected as much as possible by screwing a collar protector into it, which is not removed until the joint of casing has been landed on the casing slips.

The casing is then "floated" in to bottom. This procedure allows from 300 to 600 ft. of casing to be empty of mud fluid while the casing is being run to bottom. This reduces the weight on the elevator.

Sufficient casing is screwed together to reach bottom and the casing is completely filled with mud. The circulating head is then put on and circulation secured. The reason for filling the casing with mud before putting on the circulating head is to keep a large air pocket from being formed in the mud column. With circulation being secured around the outside, the casing is lowered to bottom. As soon as the casing shoe touches the bottom of the drill hole, the pipe is pulled up about 2 ft., thus allowing the casing to hang straight in the hole. Circulation is continued until free.

The casing is now cemented, using 500 to 800 sacks of oil-well cement, the last 200 sacks of cement being treated with a quick-hardening chemical. During the cementing process, the casing is moved within a 5-ft. limit to eliminate channeling of the cement as much as possible. When extremely long and heavy strings are being cemented, the casing is never moved after finding bottom and pulling up sufficiently to allow it to hang straight, as moving heavy strings of casing tend to loosen the collars.

After all the cement has been pumped down the casing and up around the outside, the valves on the circulating head are closed and the final cementing pressure is maintained on the casing for four days. The water string is now packed off to the surface casing. This is done by substituting the necessary casing assembly in the blowout preventer, which has already been installed on the conductor pipe. A 2-in. opening into the conductor pipe was originally provided and allows an entrance between the two casings. Immediately following the cementing of the water string, the slush pumps are connected with the opening between the casings and heavy mud is forced down behind the water string and into the formation. If sufficient mud can be forced down in this manner, serious trouble may be eliminated. The water sands will be mudded off and will not allow the hydrostatic pressure to be exerted against the casing. The gas sands will be mudded off and prevent a possible blowout between casings; also, the gas will not be allowed to "bubble up" through the cement and prevent the cement from setting.

After the casing has been allowed to stand cemented for five days, the conductor pipe is stripped off and the casing is anchored to the bottom flange by means of a landing flange, these two flanges being bolted together. The landing flange reduces the diameter to the size of the next smaller casing. The landing flange is provided with two vents that permit the escape of gas under control between the two strings of casing.

The casing being "landed," the conductor pipe is bolted to the landing flange. The conductor pipe is now reduced in diameter to the same size as the primary water string. While the primary water string is standing cemented, the 6-in. drill pipe is taken down and 5-in. drill pipe substituted. A 5-in. "kelley" replaces the 6-in. "kelley."

The hole is bailed to 1000 ft. to test the casing for possible leaks. The casing being found watertight, the cement is drilled out and 5 ft. of hole is made ahead of the casing shoe, using a fishtail bit that has had the corners cut off. The regulation fishtail bit has sharp corners that might injure the casing while drilling out the hard cement. The hole is next bailed to 1500 ft. to test the shut-off. Almost invariably, there is a considerable rise in fluid level. This is due to the presence of gas in almost all of the formations and also to the high hydrostatic head of the water

sands. The rise in fluid is not taken as conclusive evidence of failure of water shut-off, and bailed samples from top and bottom are tested for salt content and the results compared as the underground water in this field is very salty. As mentioned before, there are water sands present below the primary shut-off and therefore the shut-off test is not treated as a permanent (secondary) shut-off would be.

Having received permission from the State Mining Bureau to continue drilling ahead, a 12⅜ or 10⅝-in. rotary hole is made with 5-in. drill pipe until the correlative depth of the oil zone is reached. This hole is drilled with fishtail and disk bits. Extreme watchfulness is maintained at all times for high-pressure gas sands while making a hole of this size. The mud must be in good condition at all times.

In case 13⅜-in. casing has been used for the primary water shut-off and 12⅜-in. hole drilled, it is only necessary to ream the hole with a long fishtail bit, as the 9 or 8⅝-in. casing will have sufficient clearance without being underreamed. However, if 11¾-in. casing has been used for the primary shut-off and 10⅝-in. hole drilled, it is necessary to underream the hole to insure 9 or 8⅝-in. casing going to bottom. Underreaming is also necessary if 10¾-in. casing is to be run through 13⅝-in. casing. The underreamer[5] enlarges the drilled hole about 1 in. diam. The underreaming is usually done about every 300 to 500 ft. while the hole is being drilled.

The 12⅜ or 10⅝-in. hole is drilled to within 50 ft. of the correlative top of the oil zone and then the hole is cored continuously. When the extreme depth to the top of the oil sand is considered, it is necessary to start coring high to offset the possibilities of crooked holes. Also, the shale body above the oil zone is very thin and it is necessary to penetrate the oil sands 30 or 40 ft. until sufficient shale strata are found to insure a permanent water shut-off. The shale strata are not continuous but are lenticular. Knowing this to be the case, it is desirable to have exact knowledge of the thickness of the shale strata before running the secondary water string. On account of the heavy gas pressure within the oil zone, it is necessary to have several shale strata behind the water string so that all or any of these strata will form a bond with the cement to exclude all top water.

Having drilled and underreamed the hole to the depth where the secondary water string is to be cemented, the hole is conditioned for running casing. The same equipment and method are used in running this casing as were used with the primary water string.

The 8⅝ or 9-in. casing has a casing turner placed in the string so that when the casing is landed it will be above the highest point to which the cement can possibly reach. Also, the casing turner must be up inside the primary water string where it will not "freeze" or become sanded up. The casing turner does not prevent wear on the casing but does prevent uneven wear. The casing is usually worn out where the hole is crooked

and the wear of the drill pipe is concentrated on one side. By the use of a casing turner, the secondary water string can be rotated above the turner, thus distributing the wear evenly on all sides.

After finding bottom by circulating down the last joint, the casing is cemented, using 350 to 600 sacks of oil-well cement, and treating the last 200 sacks with a quick-hardening chemical. The cementing operations are the same as in cementing the primary water string.

The casing is allowed to stand three to seven days and is then landed in the same manner as the primary water string. The conductor pipe is again reduced to the same size as the secondary water string. The conductor pipe is built as before, except that some operators use a master gate. The outside flow assembly is used as before. In case the master gate is not used, a flow assembly is made up and stood back in the rig for instant use. The flow assembly has a swedge flange on bottom that bolts to the blowout preventer.

The hole is then bailed to 1500 ft. and the casing is tested. The cement is drilled out of the casing with a 4-in. drill pipe and 5 ft. of hole is made ahead of the casing shoe. The hole is then bailed to 1500 ft. to test the shut-off. Some operators run tubing to about 1000 ft. from bottom and the fluid is swabbed down to 1500 ft. Extreme care is taken to see that the water is permanently excluded. A rise in fluid level and the comparison of salt content from top and bottom fluid samples usually indicate whether or not the shut-off is effective. In case there is any doubt, about 20 ft. of hole is drilled, tubing run, and a production test made.

After having obtained an effective shut-off, drilling is continued. A rotating blowout preventer is now used. Essentially this blowout preventer is the same as used before with the exception of a longer body, rotating packing assembly and a bolt flange on top which allows the flow assembly to be bolted to it in case the well comes in through the drill pipe. This type of blowout preventer allows the drill pipe to be rotated freely, and moved up and down at the same time. This reduces the danger of the drill pipe becoming stuck while the well is "blowing."

A $9\frac{3}{4}$, $7\frac{7}{8}$ or $7\frac{5}{8}$-in. hole is made, depending on whether $10\frac{3}{4}$, 9 or $8\frac{5}{8}$-in. casing was used for the secondary water string. This hole is made with fishtail bits or hard rock bits on 4-in. drill pipe. Most of this hole is made with hard rock bits, as these bits wear longer and therefore do not necessitate the running in and out of the hole with the drill pipe to change bits so frequently while drilling into the high-pressure oil sands.

The 4-in. drill pipe is equipped with antifriction tool joints, subs or collars while drilling through the secondary water string. Besides causing less wear on the casing, these antifriction devices allow the drill pipe to be rotated with considerably less power. This is because there is less friction between drill pipe and casing. The strain on the drill

pipe is reduced, and consequently lessens twistoffs. The antifriction tool joints, subs or collars are used only on the drill pipe that is inside the casing. By using antifriction devices on the drill pipe, secondary water strings have been drilled through for as long as 90 days without showing any noticeable wear. By the use of ordinary tool joints and collars the casing is often worn through in 30 days.

On wells that are being drilled on top of the structure, where the distance between the primary and secondary water shut-off is less than 1000 ft., considerable hole is sometimes drilled ahead of where the secondary water string is to be cemented. After continuing into the oil zone as far as deemed safe, a cement plug is placed in the hole just below the depth at which the water string is to be cemented. The casing is then landed on this plug and cemented. After testing the shut-off, the cement plug is drilled and the hole cleaned out to bottom. This eliminates considerable wear on the secondary water string, which is the important water string. This method is dangerous to use in fields where the formation drills more easily than set cement, as the bit might sidetrack the cement plug and not follow the hole that has already been drilled. In the Ventura Avenue field, this method has been successful, because there are hard formations in the oil zone.

The rotary hole is continued until the gas pressure becomes so great that further drilling is practically impossible. During the drilling of this hole, it is often necessary to use some heavy mineral (such as hematite or barite) to give added weight to the mud fluid to hold down the gas. By the addition of heavy minerals and without increasing the viscosity, the mud fluid can be increased in weight to as much as 105 lb. per cu. ft. Also, it is not good practice to drill through the secondary water string for more than 90 days. The maximum amount of oil zone below the secondary water string that has been penetrated in the Ventura Avenue field is about 2600 ft. Wells drilled outside the proved area are often completed with 300 to 1000 ft. of oil zone.

After drilling and reaming the hole to the finishing depth, the mud is conditioned for running the oil string. The wells that have shown considerable gas during the drilling into the oil zone are loaded down with heavy mineral mud. The amount of heavy mineral that is to be added to the mud depends on the individual well, some wells being filled to the surface with this type of mud fluid.

The oil string is run in the same manner as the water strings, except that circulating is unnecessary. The blowout preventer may be left on during the running of the oil string and taken off just prior to landing the casing. The blowout preventer is sometimes removed before running the oil string, in which case a nipple, with a landing flange on top, is bolted to the landing flange of the water string. This nipple is the same size as the secondary water string.

The oil string has a steel shoe and a solid steel guide on bottom, and a sufficient amount of perforated casing to leave the top of the perforations about 15 ft. below the shoe of the last string of casing. The oil string is usually hung 10 to 15 ft. off bottom. In case the water string has been drilled through a long time, the oil string is cemented through perforations. If this is done, it becomes necessary to equip the oil string with a special type of baffle plate (cement retainer) for cementing. This plate is placed just above the top of the oil perforations and just below the cement perforations, so that it will be a short distance below the shoe of the water string when the oil string is landed.

Just prior to landing the oil string, a top flange is screwed to the casing. In case the oil string has been run through a blowout preventer, it must be removed before attaching the top flange to the casing. The oil string is then lowered until the top flange rests on the upper landing flange of the water string. These two flanges are then bolted together.

Having successfully landed the oil string, and in case the well is to be cemented through perforations, the circulating head is placed on the casing and circulation established. The well is then cemented in the usual fashion except that only 25 to 50 sacks of oil-well cement are used. The mud discharge is through the two vents that are provided for in the landing flange.

If the well has been cemented through perforations, the conductor pipe and blowout preventer are screwed to the top flange while drilling out the cement and cleaning out to bottom.

A riser nipple is then screwed to the top flange and the body of the tubing head attached. This nipple should be of suitable length so that the tubing head will clear the derrick floor. The tubing head consists of a body and top flange. The body is the same size as the oil string and is provided with slips for running tubing.

Upset tubing (2½ or 3-in.) is then run through this head to about 100 ft. above the top of the perforations. Recently some tubing strings have been run below the top of the perforations to see what effect this procedure will have on the prevailing gas-oil ratio.

After running the tubing, the top flange of the tubing head is screwed to the tubing. The slips are then removed from the head and the flange let down upon the body and bolted together. A high-pressure gate valve is screwed to the upper end of the top flange and the flow assembly is screwed to this high-pressure gate valve.

The flow assembly consists entirely of high-pressure fittings. Also, the flow assembly is bolted down by anchor bolts to the bottom flange of the surface casing.

After making all necessary preparations, the well is circulated with clear water. The circulation may be established by pumping water down the tubing and allowing it to be discharged through the openings in the

tubing head or by pumping in through the openings in the tubing head and allowing the mud fluid to be discharged through the tubing. Unless the well starts flowing during the washing process, the mud is entirely displaced to the bottom of tubing with clear water and the well is then swabbed until it starts flowing.

Wells outside the proved area are often brought in without running an oil string. Because of the hard formations of the oil zone, the walls of the open hole do not cave. This method is used so that in case the well develops water trouble, due to edge conditions, it may be remedied more easily if the oil string has been left out of the hole. Wells with over 1000 ft. of open hole have been brought in and have flowed for over two years without sanding up. In case the well is brought in "barefoot" the tubing is hung from 200 to 500 ft. above the shoe of the water string and the well connected up and brought in as above.

Conclusion

An attempt has been made in this paper to describe the equipment and methods used in the drilling of deep wells in the Ventura Avenue field, which has been more or less the testing field for oil-field equipment in California. The severe tests to which this field subjects the equipment serves as a standard, and any equipment that satisfactorily performs its duty at Ventura can be depended on for work elsewhere.

The writers believe that the equipment and methods used in this field can be successfully used wherever deep wells are to be drilled under such hazards as are found in the Ventura Avenue field.

DISCUSSION

C. P. Watson,* Fort Worth, Tex.—Perhaps one of the most interesting points in this paper is the casing program. There is doubtless no other field in the world where they have managed to solve the matter of setting these long strings of pipe, and I am sure this feature here is worthy of consideration.

R. C. Patterson, Taft, Calif.—One interesting thing in the handling of these casing strings that was not brought out is the necessity of keeping up circulation. Because of the depth of the hole, the sand and the other heavy ingredients settle quickly, and if proper circulation is not maintained at all times the string freezes. Another very expensive and tedious procedure in this development work is that practically all the casing points are determined by coring.

F. J. Fohs,† New York, N. Y.—What would be the cost for coring 100 ft. and what barrel is used?

R. C. Patterson.—I am not familiar with the procedure in the Ventura field, but in the San Joaquin fields we are using the Elliott-type core barrel. The average cost of cores there will run up to $20 a foot at depths below 4000 feet.

---

* President, Federal Royalties Co., Inc.

† Vice-president, Humphreys Corpn.

In the Long Beach field they are now coring to determine the character of a bottom water sand. Before putting a well on production they plug back with cement above this water sand.

H. E. Boyd,* New York, N. Y.—The present practice of cementing long strings of casing in the California fields raises a question in my mind as to how they prevent the casing from hanging up in the hole while moving the casing to prevent channeling of the cement. I had a little experience in the Smackover field during the Graves sand development in the early part of 1925, and I noticed that in probably over half of the wells they would stick the casing up 3 or 4 ft. above the casing seat while they were cementing; and as the immediate horizons above the Graves sand carried an abundance of water the result was that within a short time many of the wells were producing a large percentage of water. What is the cementing practice in California and how is the casing prevented from freezing while cementing, as it did in many cases at Smackover?

R. C. Patterson.—A great deal depends on the driller who watches the freedom of his casing by moving it up and down at short intervals.

C. P. Watson.—Do those strings float in?

R. C. Patterson.—They float all casing adapting the gravity of the mud to the local situation. If the mud is gas-cut they increase its weight; otherwise, they use the mud made in drilling.

F. J. Fohs.—Are special methods being used in the Logan County field of Oklahoma?

J. B. Umpleby,† Oklahoma City, Okla.—I have been through the Logan County field very recently and think there are no special methods being used there. We have adopted much heavier rotary equipment during the past two years. Instead of two 40-hp. boilers carrying 120 lb. of steam, best practice now calls for three 90-hp. boilers carrying 200 lb. of steam.

F. J. Fohs.—Are they using electric drives?

J. B. Umpleby.—Electric drives are being used more and more where electricity is available, in order to decrease cost. One company using electric drives claims that costs have been cut to about one-fifth. They are also trying internal-combustion engines to a much greater extent than heretofore; also Diesel engines. Small Diesel vertical engines of 125-hp. units are being put out. These are being experimented with but many object to them because of too many working parts.

F. J. Fohs.—I notice, in this paper, some special methods for keeping the hole straight. Are there any improvements in the methods of surveying deep holes to determine whether they are straight or not? Last year we had a deep hole in the Gulf Coast, and we would have liked very much to know the position of the bottom of the hole. We consulted one of the principal engineers in California and he said his method was not sufficiently advanced to give us the desired information.

D. C. Barton,‡ Houston, Tex.—They are attempting to survey wells in Oklahoma with the seismographic method. They put the receiver of a seismograph down the well. It is theoretically possible, but practically it is a question of what accuracy is obtainable.

---

* Henry L. Doherty & Co.

† President, Goldelline Oil Corpn.

‡ Geophysical Research Corpn.

I have not talked with the operators, to learn their technique. I do not know what results have been obtained. It is perfectly feasible theoretically. You can take four points, north, east, south and west of the well, and set off small charges there; the geophone dropped down the well will record the earth wave and from the time-velocity relations, it should be possible to calculate the distance of the receiver from the four points with an accuracy, I should think, of some 50 ft. You can put your receiver (geophone) down any depth you want. I might say the sensitive receiver of the G. R. C. seismograph is a small thing a little bit larger than an ordinary water glass, on the end of a cable, and it can be dropped or run out anywhere that you can run out or drop a cable. A small varying electric current is generated in the receiver by the earth wave and carried by the cable to and is recorded at the surface. There are no theoretical reasons why you cannot put the cable down any depth, and by repeated observations at various depths map the hole with reasonable accuracy.

C. V. Millikan,* Tulsa, Okla.—One contractor has ordered a rock bit 11 ft. long with the one idea of keeping the hole straight. So far as I know, this has not been received or tried.

---

* Petroleum Engineer, Amerada, Petroleum Corpn.

ENGINEERING ROUND TABLE

Summary of Discussion on Petroleum Engineering Problems

By H. H. Hill,* Chairman

(New York Meeting, February, 1928)

The Round Table Discussion on Petroleum Engineering Research was planned for two purposes. First, to review the work that has been done by petroleum engineers during the past few years on problems that have confronted the industry and, second, to suggest new studies that should be made either on the problems that have been the subject of research during the past or on problems that have arisen only recently. It was believed that by holding an informal discussion of the problems in which the petroleum engineer is vitally interested it would be possible to bring out new ideas as to the relative importance of the different problems that should be studied and to suggest new methods for attacking some of the problems that have resisted the energies of research workers throughout the industry. It was also believed that by arranging for an exchange of experiences between the different engineers it would be possible to prevent a large amount of duplication of effort in conducting research work. Those engaged in petroleum engineering research realize that there is a broad field for study and by coördinating the work it will be possible to obtain the maximum amount of information in the shortest possible time.

In planning the program on Petroleum Engineering Research, nine subjects were selected for discussion and each was assigned to a man who is doing work on that subject. These men were asked to lead the discussion on the problem assigned to each one. An effort was made to choose problems of a practical nature and upon which considerable work is being conducted at the present time. Some of the men who were asked to lead the discussion were unable to attend the meeting but most of them submitted a written discussion of the subject assigned, with the result that there was a discussion of eight of the nine problems. Professor Uren, who was asked to lead the discussion on the subject of Recent Developments in Methods for Reducing Gas-oil Ratios, was unable to attend the meeting and advised that he did not have any new ideas to contribute.[1]

---

* Chief Petroleum Engineer, U. S. Bureau of Mines.

[1] See paper presented at Fort Worth, on page 146.

There was a good attendance at the meeting, engineers being present from California, Wyoming, Montana, New Mexico, Texas, Oklahoma, West Virginia, Kentucky, Pennsylvania and New York. Almost everyone present entered into the discussion at one time or another and it was necessary for the chairman to limit the discussion a number of times rather than to invite the members to participate. Although interest was shown in all subjects, there was the largest amount of discussion on the subjects of repressuring and geophysical prospecting. Due to the limitation placed on the amount of material that could be published, it was necessary to eliminate a part of the discussion in preparing the final report of the meeting.

Mr. Fohs presented a summary of the use that has been made of geophysical instruments in locating oil deposits. He discussed the principles on which the different instruments are based and the conditions under which each type can be used to best advantage. He called particular attention to the fact that some 30 salt domes have been located on the Gulf Coast in the last four years by geophysical methods and at least five new oil pools were found during the past year. Mr. Fohs also briefly reviewed the use of geophysical methods for locating structures abroad. In the discussion that followed, Dr. Barton stated that he was of the opinion that in the Gulf Coast, the use of seismic methods had speeded up the discovery of salt domes by 100 years but in other areas geophysical methods have not given as good results.

Mr. Wood submitted a written discussion of the subject of Bottom Hole Temperatures and their significance in the production of oil. He called attention to the effect of temperature on the viscosity of oil, its relation to the deposition of paraffin and to the amount of gas held in solution by the oil. He also pointed out that temperature measurements are valuable in studies of underground conditions and of production problems. A considerable part of the discussion that followed the reading of Mr. Wood's summary related to methods of heating the oil sands as a means of eliminating paraffin deposits and increasing production. It was brought out that a number of the methods that have been tried have not given satisfactory results.

The discussion of Bottom Hole Pressures was very brief because Mr. Bennett, to whom the subject had been assigned, was unable to attend the meeting and the engineers present had not secured much data on that subject. Mention was made of the work that is now under way in the Salt Creek field and the value of such information for use in connection with studies of the gas-lift and repressuring.

Mr. Beecher reviewed the work that has been done on the problem of increasing the recovery of oil by repressuring and called attention to the importance of making a careful study of the area before starting repressuring operations. He emphasized the importance of maintaining

pressure during the early life of a field because the oil is then in a more fluid state on account of dissolved gas, and the maximum energy can be obtained from the gas returned to the sands. He discussed the advantages of gas as compared to air as a repressuring medium and pointed out the value of agreements between the operators in order that entire pools may be treated as a unit for repressuring purposes. The discussion that followed Mr. Beecher's summary related to the importance of determining the characteristics of the sand, the extent to which the oil is changed by the introduction of air and the possibilities of using some material other than air or natural gas as a repressuring medium.

Mr. Millikan discussed the method of intermittent injection of gas as the most promising new development in the use of the air-gas lift. He called attention to the possibilities of the method as a means of saving gas but also pointed out that where recycling is practiced it has certain disadvantages in that it upsets the uniform operation of the compressors. He emphasized the need for more data on the effect of velocities and pressures for the purpose of determining the time during the life of a well that the gas-lift should be used. In the discussion that followed attention was again called to the possibilities of intermittent injection of gas as a means of increasing the efficiency of the gas-lift.

Mr. Knappen submitted a written discussion of the problem of Hydrogen Sulfide Corrosion in West Texas. He called attention to the conditions under which corrosion takes place and pointed out the methods that are being followed in combating hydrogen sulfide corrosion. One company is purifying the gas by scrubbing it with a solution of soda ash. It was hoped that there would be a general discussion of the subject of Corrosion of Oil Field Equipment by Hydrogen Sulfide, but those attending the meeting were of the opinion that the worst conditions are encountered in West Texas and any methods that can be used to good advantage in that area will be applicable to other sections of the country.

Mr. Newby reviewed the recent work that has been done on water-flooding in the Bradford field and called attention to the importance of learning more about the water intakes and the character of the sand. He pointed out that the use of soda solutions for increasing the effectiveness of water-flooding had not given positive results. On the other hand there is no evidence that the sands have been plugged to any extent as the result of possible precipitation by chemical action between the soda and the calcium salts contained in the sand or in connate waters. Mr. Newby also discussed the five-spot plan of development whereby four water wells are drilled for each oil well. This method is somewhat more expensive than the old method but gives quicker returns in that properties will be depleted in from 4 to 6 years instead of from 16 to 30 years under the system that has been followed in the past.

There was not sufficient time at the meeting to discuss the subject of Deposition and Removal of Paraffin from Oil Wells, so Mr. Brewster submitted a written summary of the work that has been done on that problem. He called attention to the different methods that have been used for removing paraffin from wells and emphasized the need for developing methods that are not too expensive to be used for small wells.

Most of the engineers attending the Round Table Discussion were of the opinion that arrangements should be made for a similar session at the A. I. M. E. meeting next year.

Chapter VIII. Petroleum Engineering Problems

Round Table

Geophysical Prospecting

H. H. Hill.—I believe that as petroleum engineers you are all more or less interested in geophysical prospecting. A large number of the papers that have been written on that subject are too detailed or too much involved to be of much value to a person who is not familiar with the subject, so I suggested to Mr. Fohs that he might bring us something that we could all understand. As I take it, we are interested in learning something about the different methods, the places where they have been used, their limitations and in general whether they have given satisfaction in locating oil deposits.

F. J. Fohs,* New York, N. Y.—I will briefly summarize some of the results as I see them from my practical contacts with them and my discussion of the subject with some of the more important men both in this country and Europe.

Geophysical Methods

1. *Seismographs:*
   - A. 1. Sonic refracting seismographs of Karcher, McCullom and Reiber. For rapid reconnaissance and also for detail—perhaps, the best type of instrument.
     2. Mechanical refracting seismographs of the Weichert-Mintrop type.
   - B. 1. Sonic seismographs using reflected sound from contacts of sufficiently unlike beds where latter are thick enough, being used for detail of both salt domes and ordinary structures where a good reflecting key bed occurs.
2. *Torsion Balances:*
   Made in three sizes with greater portability and loss of but 20 per cent. in medium size and loss of 40 per cent. efficiency in smallest size.
   - A. Used to best advantage in detailing salt domes, in noting anomalies of deep-seated structures of the Edgerly, La., type (but not always certain here and dependent on interpretation which involves both experience and the human equation to a large degree).
   - B. Used to advantage in mapping faults where a lime or other denser bed occurs upthrown, and the topographic irregularities are not too involved.
   - C. Of use where buried granite plugs and buried-hill structures occur as in the Western Texas fields.
   - D. Believed of little use for other types of structure.
3. *Magnetometers or Variometers:*
   Now built horizontal and vertical with declinometer combined in one instrument.
   - A. Practical in mapping granite or basic igneous rock plugs and intrusions, or of detritus therefrom.
     Adams has recently demonstrated definite results in mapping the well known Panhandle arch.

* Vice-president, Humphreys Corpn.

B. An aid in mapping faults, but slow and expensive for this purpose.

C. One advantage in the use of both magnetometers and torsion balance over the same area lies in the magnetometer being able to determine the portion which contains the igneous plug as distinguished from that portion of the dome which does not.

This is of special value in domes in areas where there are basalt or other igneous intrusions for determining whether or not in advance the dome is too badly cut by such intrusions.

D. For other purposes the seismograph and torsion balance now are superior.

4. *Electric Methods:*

A. These make use of alternating or direct current. They depend on the conductivity of different minerals and rock—petroleum being a nonconductor, oil sands sometimes a conductor, and salt water or salt sands a good conductor. Generally speaking they are more serviceable in locating ores than oil deposits.

B. Most of these methods make use of alternating current and are modifications of Professor Schlumberger's work. Under this head come the Elbof method, which attempts to locate oil directly by the nonconductivity of petroleum, and the Lundberg method which attempts to locate it indirectly by mapping the outlines of a petroleum deposit by use of the conductivity of the high peripheral salt-water-filled inclined beds. Salt domes heretofore unknown in the upper Rhine basin have been located by Schlumberger partly with the aid of his method.

C. Direct current is used by Zuschlag for indirect determinations.

D. None of the electrical methods have been sufficiently perfected to make them trustworthy for oil work, though improvements will undoubtedly come. The Institute session on electrical methods gives every indication that their application is theoretically possible and development of application technique only a matter of time. Both seismographs and torsion balance, indirect though they are, are more serviceable at the present stage. Further research is earnestly recommended.

5. *Radio:*

A. The direct use of Hertzian waves in the location of oil deposits, while attempted, has as yet proved of no consequence.

B. It is used to advantage for signalling, in both seismograph and torsion balance work, and for determining instant at which shots are fired in seismograph work. It has been found that the frequency band of 2250 to 2750 kcs. (133 to 100 m.) is most suitable wave length with voltages up to 250 watts, and the next best is that of 2850 to 4000 kcs. (105 to 75 m.) and it has been so recommended to the Radio Commission.

Distances worked are from 3 to 12 miles.

6. *Radio Activity:*

Experiments continue abroad in this and Ambronn gives a discussion of them. Nothing practical as yet for oil. The Mellon Institute is said to be conducting experiments.

7. *Use and Results in this Country:*

Some 30 salt domes have been located in the Gulf Coast in the last four years by seismograph or torsion balance or both; a few additional may be under cover. Oil has been located with greater facility, both on old and new domes, by their aid; at least five new oil pools—Starks, E. Hackberry, Fausepoint, Sorrento and Allen—were found in the past year, and the Longpoint sulfur dome was also found, with perhaps a half dozen other oil pools in previous years. Since October, 1927, four

domes (one already drilled into salt) were located in Louisiana by seismograph and one in Texas by torsion balance. The development of the Gulf Coast region has been greatly speeded by these methods—and the number of dry holes probably reduced half or more. While fewer dry holes are necessary to locate a new salt dome outlined by these methods, the great variation in conditions on the periphery of the dome still make a large number here unavoidable.

Outside of the Gulf Coast and in California, where they were only put into use a year ago, little directly has been accomplished by these methods.

The torsion balance in West Texas fields has frequently been worthless, chiefly because we have not known how to interpret results; gravimetric highs are reported at Big Lake and McElroy. In the Panhandle area it is helpful because of the buried igneous hills.

According to a recent summary by Donald C. Barton[2] the number of geophysical troops in use in the oil fields of this country are as follows:

	Regular	Experimental
Seismograph	15	13
Torsion balance	87	6
Magnetometers	86	4
Electrical		3
Total	188	26

8. *Use Abroad:*

The Government of Italy is employing German engineers to attempt location of structures in the Poe Basin, making use of seismograph, torsion balance and electrical methods. In Spain these methods are being employed; also in Northern Africa; in Rumania; in Persia and Irak. The Anglo-Persian Co. in Persia is experimenting with practically all methods. In Mexico, the results appear to have been mixed from both torsion balance and seismograph, though the torsion balance has been effective for its southern salt domes.

Noteworthy Publications:

Richard Ambronn's book on Applied Geophysics and Gutenberge's Handbook of Geophysics, of which three parts have thus far been published. Both of these works are in German.

Barton's paper presented at this meeting[3] and the Shaw and Lancaster-Jones papers[4] are very helpful on the use of the torsion balance. Dr. Pautsch has written a book in English on geophysical methods, but it is inferior to Ambronn's. Carl C. Adams' recent article on the Panhandle Arch in the *Oil & Gas Journal* is of interest on magnetic surveying.

Barton gives a rather complete bibliography in his paper in *Economic Geology* for November, 1927 in which there is a good brief review of geophysical methods.

D. C. Barton,* Houston, Texas.—I have a few small points to make in connection with Mr. Fohs' paper. At Homer, La., some experimental work was done to see what the reflection method could do on that type of structure and it put the fault about 2000 ft. away from where the Amerada geologist had put it, on the basis of subsurface correlation some years before, but it happened he had not been keeping a record of the development there. He went back and checked up; his original fault was put in on the basis of some half-dozen wells; he got about 20 to 30 wells drilled since

* Geophysical Research Corpn.

[2] *Economic Geology* (November, 1927).

[3] A. I. M. E. *Tech. Pub.* No. 50.

[4] A. I. M. E. *Tech. Pubs.* No. 74 and No. 75; see also *Mining Magazine*, London.

then, and moved the fault 1500 ft. toward the position of the fault according to the seismic method, and the accuracy with which the seismic measurements had been made did not allow the location of the fault within 500 feet.

It is interesting to notice that the Gulf Production Co. and Roxana Petroleum Corpn., who have used the torsion balance most, are reported to be having big balances made to order instead of taking the little balances. It is the new people who are taking advantage of the small instruments rather than the old people who have been using the instruments. The Roxana was asked if it would swap a big balance for a little balance and said it would be willing to swap a little one for a big one, but not the reverse.

The Haalck magnetometer has been tried on the Gulf Coast; and, probably due to some small feature, it apparently has not been successful. I understand that the Gulf Production Co. has stored its Haalck magnetometers.

The electric method has interesting possibilities because it is the only one of these methods that acts on any principle that allows the direct determination of oil, on account of the very high resistivity of oil, and there is the theoretical possibility that the method may be developed ultimately so we can tell where the oil is and not worry about mapping structure and hoping that the oil is where it should be on the structure. The Elbof people claim they are able to do it, but there seems to be great question about it. The Gulf Production Co. gave them a tryout and say that although there are interesting possibilities in the method, it was not worth while fooling with at present. The Humble Oil & Refining Co. also has tried the method out; it was used in the Kingsville field, which is somewhat spotted, and I gather that there have been about as many successes as failures and about the same degree of success as if the predictions had been based on chance.

The Schlumberger method has not been tried out as much as it should be on oil types of structures. It has done extremely interesting work on salt domes in Rumania and Alsace and shown the capability of handling the situation there, but no method will ever have the brilliance of the seismic method in hunting salt domes when you get up to 300, when you can pick down to 5000 ft. with a cost of 4 c. an acre. You will never have a method that will have the clairvoyance in looking down into the ground. The method has done interesting work on faults although not in oil work. Some of the work of the Swedish methods looks very interesting and they too should be tried out further on the oil types of structures.

Mentioning Alsace—a salt-dome geologist, if he had ever examined the core drilling, should have picked up the Ensisheim salt dome. The geologists had tried to fit the results to some orthodox trends. The results of the Schlumberger survey lined up the results of the drilling on a wholly new trend and on the prolongation of that trend a further Schlumberger survey picked a wholly new salt dome; the salt on this dome has been drilled into since Mr. Fohs was in Europe.

In regard to Ambronn's book; it is now being translated into English by Dr. Cobb, of the Geophysical Research Corpn. Before I left Houston, I read the first third of the manuscript of the translation.

The radio in the seismic method is merely the timing element; used for the communication and between the various units of the troop, particularly with the firing unit and for the instantaneous transmission of the time of the explosion to the receiving units.

In the Gulf Coast the seismic methods have really speeded up the discovery of salt domes 100 years. I do not believe that without these methods we would have had all the domes we now know in 100 years from now. The seismic and torsion balance methods furthermore allow us to locate our wells fairly accurately, so that we know if we want to put a well on top of a dome we can have about 100 per cent. accuracy in getting it on top.

We are also interested in locating wells on the flanks of domes. On some domes we want a well to be within 500 ft. of the edge of salt and yet not go into the salt or cap. When you have no surface mound and no geology, it is a difficult task to make such a location there. The torsion balance can get it in that 500-ft. zone with about 50 per cent. accuracy and it will not be far out on either side of that zone in the 50 per cent. of failure, and that is about as close as the irregularity of a dome will allow.

In Cook County, Texas, the highest well in the county, except one that is dubious, is a torsion balance well located away off the axis of where the geologist put the structure.

In West Texas we are up against complicated geology. I think that we must have a structural situation comparable to that of the Bend Arch where there is an unconformity in the Pennsylvanian with a big break in the structure above and below. I suspect that we must have some such condition in the Winkler Pecos Counties area. My suspicion is based on the results of torsion balance surveys.

One difficulty at present is that the torsion balance sees down deeper than the geologist is interested in at present. The anhydride mixes things up a little bit, but is not so serious as it might be, and the oil men are worrying too much about the effect of topography. Most of our oil is not in mountainous topography and in most places where we have oil, we do not need to worry about the effect of topography on the torsion balance. In West Virginia that might not hold, but in the Mid-Continent the topography need not worry the torsion balance man too seriously. Or rather, the effects of the topography may worry the torsion balance man technically but not preclude the satisfactory use of the method.

In southern Oklahoma, if the area were covered with Woodbine sand, we would have picked up the Healdton, Hewitt and Robinson fields like a lighthouse on a clear night. As a matter of fact, on the 180 miles of traverse there were 11 first-class prospects on the basis of the torsion balance results. If two wildcats were allowed to each prospect, 30 per cent. of those wells would have discovered important production and 30 per cent. of the prospect of the wells would be on structures that have not been drilled as yet, and as far as is known, none of those 11 first-class prospects would have been false. If my memory is correct, there were some 22 second-class prospects. If two wells were allowed to a prospect, 50 per cent. of the wells would be on prospects that have not been drilled as yet and 11 per cent. of the wells would have discovered production.

Outside of the Gulf Coast the geophysical methods do not give as good results in indicating where to locate a well as they do on the Gulf Coast. They give the approximate position of the crest, although, as yet, that is a bit hazy.

H. H. Hill.—I understand that statements have been made that geophysical methods can be used for finding the area of a pool, by determining the position of the edge water. If such is the case the petroleum engineers would be benefited in their work of controlling water that enters the wells.

D. C. Barton.—I had not heard of that. It looks to me as if that would be a rather delicate job. I was talking to Mr. Leonardon of the Schlumberger company, and he said the oil sands were fair conductors according to their experience. There is so much salt water in and around most sands; when you think of the percentage, the oil in general is so insignificant in comparison to the saline waters in sands and to the saline wet clays and shales, that the determination of the edge-water line would look rather dubious to me.

If there was only one sand in the whole section with oil here and salt water there (indicating), it seems to me that it might be possible to do some such thing, particularly if the sand were rather shallow. But even if a method of direct indications of

the presence of oil is developed, it seems to me doubtful whether the results will be clean cut and definite enough to give more than a vague indication of the limits of the oil pool.

C. E. Beecher,* Bartlesville, Okla.—You gave the number of instruments of various types that are now in use. Do those figures in any way indicate the relative importance of the instruments?

D. C. Barton.—No. It is just that they work differently. In the torsion balance work some companies run the instruments in groups of 2, 3, 4 or 5, each of which would then work like a seismograph troop, which normally works with one shooting unit and three receivers. The seismograph has much greater speed on reconnaissance for salt domes, in the Gulf Coast; the average speed for all companies on reconnaissance for salt domes I imagine would be perhaps 150,000 acres, while one troop of the G. R. C. kept up an average of 300,000 acres a month for several months. A torsion balance has a speed of perhaps ½ square mile a day on reconnaissance. On the other hand you might compare the amount of money spent in the operation of seismic work compared to torsion balance. For a time, for example, the Gulf Production Co. was spending some $75,000 per month on the seismic work, and some $20,000 on the torsion balance work, and now is probably spending somewhat more on torsion balance work and somewhat less on seismic work. The Roxana Petroleum Corpn. has been spending considerably more on torsion balance work than on seismic work.

E. R. Lilley,† New York, N. Y.—What is the size of the fault there and what is the character of the sediments in that section?

D. C. Barton.—There are sands and clay and it is a sizable fault, with a throw of some hundreds of feet, but I am not particularly familiar with the details of the geology of the Homer dome.

A. Knapp,‡ Philadelphia, Pa.—I was puzzled as to how they find it, because my impression was that it was a more or less unconsolidated formation. They may have gone to the chalky portion which is deep.

D. C. Barton.—A little depth does not worry them seriously. In the Gulf Coast they have gone down 15,000 ft., and in ordinary work down to 5000 ft.

E. R. Lilley.—What is the difference in the character of the material?

D. C. Barton.—They must have had some hard ("high-speed") bed. We had a prospect east of Houston, the Hunting Bayou prospect, where we ran first a torsion balance and then the seismograph. The latter gave a distinct reaction to a semi-high-speed bed at moderate depth. We had drilled three deep tests in the area; but that bed was nothing that the driller noticed and we could not identify it from the driller's log, though we had been given its approximate depth; there was enough alternation of sands and clays with no one bed showing any particular peculiarity that would allow us to identify it as the bed setting up the refraction of the earth wave.

Bottom Hole Temperatures

F. E. Wood,* Casper, Wyo. (written discussion).—During the past few years in the Salt Creek field, a great number of temperatures have been taken in wells at the depth of the producing Second Wall Creek sand. These temperatures vary from 95° F. to 105° F., depending on the depth; the greater the depth, the higher the temperature.

---

* Production Engineer, Empire Gas & Fuel Co.

† Associate Professor of Geology, New York University.

‡ Petroleum Engineer, United Gas Improvement Co.

§ Petroleum Engineer, Midwest Refining Co.

In 1921 and 1922, C. E. Van Ostrand, of the U. S. Geological Survey, took numerous underground temperature readings and his results were almost identical with the recent work. As many of the earlier and recent temperature measurements were made in the same wells, it proves that the production of oil and gas during the period from 1921–22 to 1926–27 had no effect on underground temperature.

Temperature has an important influence on the viscosity of oil. Within the range of temperatures in the Second Wall Creek sand the viscosity varies as much as 18 per cent. The viscosity of other oils is affected to even greater extent through the same range in temperature. Since the forces tending to hold oil in the sand are reduced with a reduction in viscosity, the higher the natural formation temperature. the higher the yield of oil.

Paraffin deposition is dependent on temperature. If the formation temperature is higher than the melting point of paraffin, no deposition occurs. On the other hand, if the temperature in the formation is below the congealing point of the paraffin it is necessary to take precautions to keep it in solution to prevent unnecessary production difficulties.

The amount of gas held in oil in solution is affected by the formation temperature. The higher the temperature, the smaller the amount of gas in the oil. As gas is the chief expulsive force of oil the ultimate yield is dependent on the formation temperature. As a suggestion for investigation, it may be found that formation temperature is a possible explanation for fields which have free gas on top of the structure, surrounded by oil, in comparison to oil fields which do not have a free gas area.

There has been considerable published information on the theoretical cooling effect on producing formations of gas entering a key well under pressure in a gas-drive system. Actual measurement, however, indicates that the temperature in the sand remains unchanged with the introduction of gas. Gas preheated before entering a well does not affect the formation temperature.

Undoubtedly formation temperature has an effect upon the character of oil and gas produced as well as being particularly responsible for the existence of oil and gas.

In all, temperature has a very important influence on the production of oil and gas and the state in which they are found. Temperature has been a factor generally overlooked in production problems but will play a prominent part in analysis of underground conditions in the future.

J. W. Steele,* Casper, Wyo.—The work of Dr. Van Ostrand was continued with an idea of obtaining more complete information in the field and having in mind that possibly the results obtained could be taken advantage of in eliminating paraffin troubles. So far the results are encouraging, but they are being used in a little different way at the present time.

The paraffin problems opposite the sand itself are not so serious as was anticipated, so the next step was to use the sand temperatures in connection with the gas-drive of the field. Several interesting things were found in trying to determine a crucial temperature point for the gas entering into the sand and the final result shows that no advantage is gained in trying to preheat the gas on the surface before it enters the wells.

H. H. Hill.—How high did they heat the gas before introducing it?

J. W. Steele.—As high as between 800° and 900° at one time.

H. H. Hill.—What was the temperature at the point it reached the sand?

J. W. Steele.—Practically the sand temperature. The temperature of the well at a depth of 100 ft. is approximately the mean annual atmospheric temperature of the

* Supervisor, U. S. Geological Survey.

country, and the trouble seems to be that it is impossible to get a sufficient heat into the gas to do any good in raising the temperature of the formations. The small amount of heat that is put into the gas is simply dissipated before it comes to the sand itself.

That has also been demonstrated by putting in a cold gas, and finding it has approximately the same temperature as the sand by the time it leaves.

An attempt was made to verify this result by using steam. A flash boiler was used, similar to the steam boiler used in an automobile, and the steam was taken to the surface of the sand, but it had no effect in raising the temperature of the walls of the well. This was simply another check on the results obtained with both the warm and the cold gas that had been put into the sand.

There was an idea that possibly by trying to put the gas into the sand under high pressure there might be a chilling effect opposite the sand due to the expansion of the gas when the pressure was lowered to the sand pressure. Conclusive results have not been obtained but further work will be done during the coming summer.

A. Knapp.—Mr. Steele's remarks would lead us to wonder how they are able to melt sulfur in sulfur wells with the aid of steam.

D. C. Barton.—They do not use steam, but superheated water.

H. H. Hill.—Neither gas nor steam has a very high specific heat and I think that accounts for the difficulty in getting the heat to the sand.

D. C. Barton.—I did not get much data about it but I heard that the Marland Oil Co. had brilliant success in shooting hot flue gas into the oil sand in the Coffeyville area.

C. E. Beecher.—The sand is shallow there, only about 75 ft. below the surface.

D. C. Barton.—How long did they try heating in Salt Creek? How long did they shoot the gas in to see what the effect was?

J. W. Steele.—I think some of the tests were continued for 21 to 27 days. Others were of shorter duration. I have forgotten the exact periods of time.

D. C. Barton.—In sulfur mining where they are "steaming" with the superheated water, it is at a depth of 1000 to 1700 ft. They have to pump down the hot water for quite a long time before they get the temperature of the sulfur-bearing zone up to the temperature that they require, about 237° F.

J. W. Steele.—There was no trouble in getting the superheated steam down to the sand and raising the temperature of the recording device, but that was about as far as the effect went. One trouble was that the flash boiler had too little capacity to do much good over any period of time.

D. C. Barton.—Were there any calculations to see how long it would take to warm up the oil sand?

J. W. Steele.—I do not know whether they have gone that far. Undoubtedly they have but I do not have the figures.

Bottom Hole Pressures

H. H. Hill.—A subject that is closely related to bottom hole temperatures is that of bottom hole pressures. I understand that some of the companies are making a study of this subject in connection with their work on the gas-lift. I was hoping

that Mr. Bennett, of the Marland Oil Co., could be present in order to give us some of the results of his experiments, but unfortunately he was unable to be here. The only other company that I know of that is doing much work along this line is tht Midwest Refining Co. in the Salt Creek field, and I believe that its experiments have just started.

J. W. Steele.—Our work has just started. The Midwest and the Bureau of Mines are doing some work on this problem, but the results have not been conclusive and they are not giving out any information at the present time.

C. E. Beecher.—Do you know what method they are using?

J. W. Steele.—The bomb method—pressure gage and bomb. The Midwese company is also developing an electrical recording pressure gage, so that the pressure will be taken opposite the sand but will be recorded at the surface.

C. E. Beecher.—I think that in addition to having value in connection with gas-lift work, "bottom hole pressures" would be especially valuable data to have in connection with repressuring during the early life of a field.

Increasing the Recovery of Oil by Repressuring

C. E. Beecher, Bartlesville, Okla.—Repressuring or maintaining pressure during the early stages of development I consider the most important advance in the science of applying pressure for increasing the recovery of oil. By the early application of pressure the maximum energy can be obtained from the gas returned from the sands. By-passing or channeling would not take place as rapidly as when repressuring old fields because the sand would be well saturated with oil. The oil would still contain a large per cent. of dissolved gas and therefore would be in a more fluid state. Under these conditions the energy transmitted to the oil by the gas under pressure should move more oil and with less energy than in the nearly exhausted fields. Some form of coöperation or unit development will be necessary if the maximum benefit is to be obtained by maintaining pressure. The advantages of this method are so evident that I believe most operators will enter into an agreement for coöperative development.

Since I have nothing of particular interest to offer regarding the repressuring of old fields, I will briefly outline some of the factors to be considered for this method of recovering oil.

It is essential that a careful study be made of the area to be repressured; the depth, thickness and character of the sand are important; in general, a sand found at a shallow depth will require less pressure than deeper sands. A thick sand body will be expected to take a much larger volume of air or gas than the thin sand body. The character of the sand is most important; if the sand contains a large amount of cementing material the porosity is probably low and high pressures will be required. Shale breaks within the sand body may separate layers of sand of different porosities and the results of repressuring will be to drive the oil from the layer of sand having the greatest porosity without affecting the remaining portion of the sand.

The character of the oil and the amount removed from the sand are important considerations. In general, a thin oil or one of low viscosity can be moved through the sand with less resistance than a heavy viscous oil. The amount of oil removed gives an indication of the productivity of the sand and may also indicate the characteristic of the sand. A coarse sand of high porosity will usually produce more oil than a tight sand of low porosity or than a fine-grain sand having the same porosity.

Knowing the amount of oil removed, some estimate can be made of the oil remaining. If this latter figure is large the project is naturally more favorable.

It is important to consider the association of gas or gas-bearing sands in connection with the oil sand. In some areas the upper portion of the sand carries practically nothing but gas or a gas sand is located close to the oil sand. It may be separated by a break so small that it would not be detected when drilling or a break which is too small for the purpose of landing a string of casing or using a packer. Where conditions of this character are found, gas or air forced into the sand may migrate through the gas-bearing portions without having any appreciable effect upon the oil.

Water is a hazard in any repressuring project. The amount, character and source of the water should be determined before repressuring, if possible. Repressuring may result in an increased production of water without an increase in oil production or an increase in both. Water is always an emulsion hazard in repressuring projects, using either air or gas. When using air the presence of water is likely to result in serious corrosion conditions. I have observed balls and seats made of stainless steel that have been badly corroded after being in a well only three days.

Where structural conditions are pronounced more attention must be given to the proper location for pressure wells. The top portion of a structure is likely to be gas-bearing and the sand more porous. Under such conditions pressure wells should give the best results when located down the structure near the edge-water line rather than on top of the structure in the gas area. I am familiar with one small structure in which oil was found over the entire structure. Repressuring operations resulted in the pressure traveling along the top of the structure and affecting production in wells located ¼ mile from the pressure well, while wells offsetting the pressure well were not affected.

Where the property being repressured is comparatively small and there are indications of the pressure benefiting offsetting operators, vacuum is frequently used on the line wells as a means of protection. It is my opinion that vacuum in general will cost more than the benefit derived from its use will justify. If the adjoining producers will not enter into an agreement for repressuring, I believe the best method is to reduce the pressure in the vicinity of offset operations by reducing the volume of air or gas being forced into the sand. I know of one instance where vacuum has been applied to line wells for protection purposes. It resulted in a rather large increase in production which could not be sustained and after a few months the production was back to approximately the same figure as before applying vacuum.

Preliminary pressure tests are desirable when the area to be repressured is large and will require the installation of considerable machinery. By selecting representative wells, tests can be made to determine the pressure at which the sand will take air or gas, and, the volume that can be delivered to the sand at various pressures. By observing offset wells the direction in which the gas or air is traveling can be determined, also the rate of travel. After these data have been obtained, it will be possible to correctly design the repressuring plant. I know of one instance where preliminary tests saved many thousand dollars in the design of a pressure plant. I believe there is a tendency to overpower the average repressuring project.

The question is frequently raised as to the relative merits of air or gas for repressuring. If gas is available in sufficient quantities it will be used without giving a thought to the use of air. Unfortunately most of the repressuring work is being carried on in exhausted fields where gas is no longer available in sufficient quantities and on many of these properties it is necessary to purchase gas for operating the machinery.

It has been stated that increased recovery can be obtained more quickly with the use of air and that a smaller volume is required compared to gas. I have no informa-

tion to corroborate this statement. Gas has many advantages over air, such as its use for fuel, the possible reduction in the viscosity of the oil due to a certain amount of gas being dissolved under pressure, and a wider diffusion through the oil. Gas will not produce corrosion nor create emulsions where water is present to the same extent that air will. In some instances the gravity of the oil has been reduced where air is used for repressuring; in general, this will not be the case with gas. If the gasoline content is not extracted, but returned to the sand, the gravity of the oil may increase. I have been told of one instance where the increase under such conditions was as much as four degrees.

It is my opinion that a greater ultimate recovery will result from the use of gas than from the use of air. Gas has a tendency to diffuse more widely through the oil than air, and as a result should affect a greater portion of the oil. Should it be necessary to cease repressuring a property, the amount of oil recovered from that time on, I believe, would be greater if the property had been repressured with gas rather than air.

The amount of gas or air forced into the sand per barrel of oil recovered varies over a wide range. On some of the properties with which I am familiar this input gas-oil ratio varies from 450 cu. ft. per bbl. to 3000 cu. ft. per bbl. The lower figure applies to properties being repressured with gas and producing some gas; the higher figure to strictly an air-repressuring project in which little or no gas is present. The amount of channeling or by-passing that is taking place and the volume of void space within the sand which may have been occupied previously by gas, or due to the oil that has been removed, plays an important part in the volume of air or gas that must be injected into the sand to recover a barrel of oil.

By-passing or channeling of air or gas from the pressure well to adjacent oil wells is one of the most serious problems encountered in repressuring work. Various means are used to prevent such by-passing and no one is applicable to all conditions. It is frequently necessary to try two or three methods before the one best adapted to the conditions is found. Holding a back-pressure on the well to which the air or gas is channeling is a common method for overcoming this trouble. A back-pressure may be held in various ways. For example, the tubing can be raised, which will result in a higher fluid level within the well, or the pumping time or length of stroke can be reduced, which likewise will result in a higher average fluid level. Another means is to equip the well so that only a fixed volume of gas will be produced. This will automatically hold a back-pressure on the sand, the amount of which will vary somewhat with the pumping conditions. Stopcocking is another method, which has proved satisfactory in a few cases. Channeling has been eliminated in some wells by shutting them in for a few months. Another method is to vary the volume of air or gas being delivered to the pressure well. If the above methods do not prove satisfactory, changing the pressure will frequently overcome channeling difficulties. I know of one property on which several pressure wells have been changed with beneficial results and the original pressure wells are now producing considerable oil.

The average operator does not have a block of acreage large enough to conduct repressuring operations and usually finds it necessary to purchase adjacent acreage or enter into an agreement with the operators of this acreage so that repressuring will be applied to all properties. If maximum results are to be obtained an entire pool should be treated as a unit for repressuring purposes. There are several pools in Oklahoma where the operators have combined for repressuring purposes and the results have been extremely satisfactory. With one exception we have found offset producers ready and willing to coöperate in any repressuring project that appears to have merit.

Exhaust gases from gas engines or boiler flue gas has been suggested as a substitute for air for the purpose of eliminating the explosion hazard which results from air-gas mixtures. To date our experiments with the use of exhaust gas have been unsuccess-

ful because of corrosion from some of the nitrogen compounds which we have been unable to remove from the gas.

H. H. Hill.—One unusual feature that was brought out in Mr. Foran's paper on Repressuring Early in the History of the Field,[5] was the fact that the companies were able to get together in repressuring a new field. I think all the blocks of acreage indicated belonged to different companies and it was not long after the first company started repressuring one of its leases until the company across the line noticed an increase in production.

The first company was then up against the proposition of either shutting down its compressors or making some arrangement with the adjoining lessee. The two companies were able to get together and as a result they drilled a five-spot well on the line between the two properties and started repressuring there. This, in turn, drove some of the oil on toward the northeast and the second company had to make arrangements with its adjoining lessee to put another well on the line between their properties. This experience certainly demonstrates that the companies can get together on that sort of a proposition.

Referring to the question of putting gasoline into the wells that are being repressured, a prominent engineer once told me that if he had a field all to himself and was able to handle it the way he wanted, he did not believe he would ever build a gasoline plant. He would simply re-cycle the wet gas as the gasoline contained in it would aid in removing the oil from the sands. It is very possible that this gasoline going back into the sand and coming out with the oil would be even more valuable than it is as natural gas gasoline.

J. B. Newby,* Bradford, Pa.—The gravity of our oil has been distinctly decreased by the introduction of air. On one property the decrease was 3° within about four months. On another property it was reduced even more, though over a long period of time. On the property on which we had 11 interior intakes we were introducing into the intakes between 8000 and 10,000 cu. ft. of air per barrel of oil produced.

D. P. Wardwell, Casper, Wyo.—In using CO_2 you found it soluble in oil?

C. E. Beecher.—We are not making an effort to put CO_2 into the sand. That found in the exhaust gas is largely removed by the scrubbing solution.

D. P. Wardwell.—We have a well in northern Colorado that is making practically all CO_2 gas.

J. R. Reeve,† Billings, Mont.—There are certain fields in which the oil has not been associated with gas. During the early life of such fields the oil has flowed because of hydrostatic pressure. In general, can satisfactory results be reasonably expected from repressuring with air in this type of field?

C. E. Beecher.—If water has reached the top of the structure, air might be forced into the sand at this point to drive the oil towards the water. This would result in a combination flood and pressure drive from which an increased recovery of oil might be expected.

H. H. Hill.—Regarding the question of determining the characteristics of the sand before repressuring is started, there is a case in Texas where they started to put air into the wells and it was but a short time until the adjoining wells showed large quantities of air coming through. As a result they did not get much of an increase in production because the air was by-passing the oil. By taking cores of

---

[5] See p. 285.

* Vice-president, Petroleum Reclamation Co.

† Petroleum Engineer, U. S. Geological Survey.

the sand they determined that the upper portion was barren and rather porous. By drilling five-spot wells, and cementing the casing right in the sand, they have been able to increase the production appreciably. They found that the sand was not uniform but contained some shale breaks and by cementing off the upper portion and using the well for introduction of air, they got a real increase in production. I think that often in repressuring operations they do not study the sand carefully enough before they start introducing either air or gas.

Another point that was mentioned by Mr. Beecher is the change that the air undergoes in repressuring operations. In connection with our studies at the Bartlesville Station we found that in some cases where air is used as a repressuring medium, the oxygen content is reduced and the resultant product is largely a mixture of nitrogen and CO_2.

We are not certain as to whether the oil is actually oxidized and leaves an asphaltic deposit in the sand or whether the oxygen of the air acts on the mineral matter rather than on the oil. Although the gravity of the oil is reduced we have not as yet determined whether the chemical composition of the oil has been changed by the action of the air.

H. A. Wheeler,* St. Louis, Mo.—Do you shoot the air wells and does the air make its appearance as soon as the increase in production shows?

C. E. Beecher.—We do not make a practice of shooting the pressure wells if they will take sufficient air or gas at the pressure available. We have found some wells will take air or gas after shooting that would not do so before the shots. Shooting increases the cost of completing a well. The air or gas volume usually increases with an increase in oil production.

C. V. Millikan,† Tulsa, Okla.—I understand that in one of the central Texas fields, one operator is successful in blocking water encroachment by injecting gas in some of the down slope wells. The operators I know are very enthusiastic about it. I do not know the details.

Mr. Beecher, what do you think of the idea of intermittent injections of gas or air, injections for 3 to 12 hr. and then off 12 hr., or injections for one or two days and then shutting down one or two days, using the same volume of gas, but injecting it for shorter times?

C. E. Beecher.—We had not tried it. Do you know of anybody who has had any success with that method?

C. V. Millikan.—I understand one of the operators has attempted it in one of the shallow fields and we are trying it in some of our shallow wells in Texas, but the method has not been in use long enough to know whether it is of definite advantage.

C. E. Beecher.—What is the advantage of this method? I assume to prevent channelling?

C. V. Millikan.—Partly, yes, I will not say entirely that; probably on the same thought we sometimes increase production by stopcocking. The idea is to prevent the flow of gas by capillary attraction. The oil will absorb the gas and as more air is injected, it will push the oil ahead of it.

D. F. MacDonald,‡ Louisville, Ky.—In Kentucky and Pennsylvania, is it not true that there are partly exhausted oil fields close to relatively large industrial areas? Coal being relatively cheap there, would it not be possible to utilize blue

---

* Consulting Oil and Mining Engineer.

† Petroleum Engineer, Amerada Petroleum Corpn.

‡ Geologist.

water gas, which is a mixture of CO plus H_2, with the idea that it could be utilized in an industrial way, merely a case of making gas?

Of course, you must have a market for it. There is one thought connected with that. Apparently the use of air oxidizes oil and you get an asphaltic product formed to some extent, at least I gather that from the discussion. Would it not be true that the use of blue water gas would give you a different result; that is, if you had an appreciable amount of hydrogenation, you would get a lighter oil?

H. A. Wheeler.—What would the blue gas cost?

D. F. MacDonald.—I suppose about 15 c. per thousand if coal was relatively cheap. As I say, there are many fields where it would not be applicable at all because there would be no market for it, but it seems there are fields in West Virginia, Pennsylvania and Kentucky, where it might be applicable.

J. B. Umpleby, Oklahoma City, Okla.—I know of nothing exactly along that line although something comparable is being done in Oklahoma. Excess gas from the Burbank field is being carried 8 or 10 miles to the east and stored in an exhausted gas field. The gas is stored during periods of low consumption and withdrawn during periods of peak demand. The losses incident to storage are said to be negligible.

Some of the gas companies of California are seriously considering doing the same thing, using an exhausted pool as a reservoir for storage purely incidental to marketing the gas. If such gas can be made to do useful work by passing it through an oil sand incident to storage, according to Mr. McDonald's thought, the procedure would represent a high order of conservation.

C. R. Fettke,* Pittsburgh, Pa.—That is already being done on a limited scale in the Appalachian field. Several gas companies are using small depleted oil pools as storage reservoirs for natural gas and at the same time are utilizing the pressure thus built up to recover additional oil. The procedure has hardly passed the experimental stage as yet.

A. Knapp, Philadelphia, Pa.—That appears to be a practical thought. The gentleman merely suggests you borrow the manufactured gas and use it and pass it on to the consumer.

R. H. Johnson,† Pittsburgh, Pa.—While the hydrogen might not, the carbon monoxide might have a chemical activity that would not be desirable.

A. Knapp.—Recent developments have shown there has been an error regarding the inactivity of hydrogen in so-called blue gas and that much lower temperatures are operative than what was previously thought; that is, it retains what has been called its nascent condition much longer than was previously suspected.

I believe this was brought out in the manufacture of some of our new paints, which were started at very high temperatures and are now made at very low temperatures.

H. A. Wheeler.—You spoke of 72 air wells. How many acres do you give to one air well in a big field like that?

C. E. Beecher.—I cannot answer that. We have about 600 oil wells and 72 air wells in that field, but I do not know how much acreage. Where the spacing permits one air well is used for eight oil wells.

---

* Associate Professor of Geology and Mineralogy, Carnegie Institute of Technology.
† Professor of Oil and Gas Production, University of Pittsburgh.

G. O. Smith,* Washington, D. C.—Some years ago we toiled over some rather voluminous records that came in to Washington in response to a certain questionnaire. Well, the amount of knowledge that is displayed here today is very gratifying as compared with the amount of information that we received from those questionnaires.

We have learned a lot since then. It is not simply that the engineers who responded were unwilling to give the information, but they were very uncertain about where they stood on the subjects of rejuvenation and repressuring. We really have made a great amount of progress since then.

I have heard it remarked twice in these sessions and there seems to be quite a general agreement that the best way to rejuvenate a field is not to let it get old. I think both Dr. Umpleby and Mr. Beecher made the statement, perhaps in different words. We might express it, the best way to cure this dead oil is not to let it get dead. That seems to be recognized more and more, and therein lies the advantage of having back-pressure and not letting a well run wild, as was thought necessary some years ago. It was taken for granted that an oil well had to sow its wild oats, and we know that it lost a good deal of value through the process. Now we are coming to the idea that we do not have to make an oil well young again, if we only guide it aright and direct it to live a rather moderate kind of life from the very start.

J. B. Umpleby.—Very likely the questionnaire Dr. Smith sent out is largely responsible for the present state of our knowledge on this. I think it started us off.

Recent Developments in the Air-gas Lift

C. V. Millikan, Tulsa, Okla.—There is only one new development that is really promising—we have some very encouraging results from intermittent injection of gas. That is distinguished from intermittent flowing in that the time of injection of the gas is very brief—2, 3, 4, or 5 min. It is then cut off for a period of from 3 to 15 minutes. The period is not long enough for the well exactly to stop flowing; it keeps up a continuous rate of flowing, although in most cases where this method is used there is a different rate of flowing and a different pressure required for the injection of this gas.

In one well where we used it the normal operating pressure was about 200 lb. The cycle necessary to inject the gas under intermittent injection was from 90 to 300 lb., and this cycle extended over a period of some 45 min. It was not the heading effect that we usually think of in a well that does not flow steadily, just a different rate of flowing from anything we usually encounter.

The economy of this usually consists in saving sometimes as much as one-third of the volume of gas necessary for continuous flowing or steady flowing. It has one disadvantage where recycling is practiced, and most of the plants in the Mid-Continent are recycling plants, in that it results in an irregular volume delivered by the compressors and throws the whole system more or less out of its uniform running.

It is really surprising how little we know about gas-lift operations. It seems, from the experience I have had with gas-lift, that it is essentially a question of velocities. I have tried to approach the subject from this angle and I get some very confusing results.

I might mention a specific example. We had one well flowing at about 200 lb. making 900 bbl. a day at the time we ran the test. The bottom velocity there was about 9 ft. per sec. We were experimenting with velocities, so we started holding

* Director, U. S. Geological Survey.

back-pressure, and by holding 60 lb. pressure on the trap, we reduced the top velocity to somewhere around 30 ft. per sec.; and we have not yet affected the production.

We have another well in which the top velocity was figured better than 100 ft. per sec. and yet when we put some 10 lb. pressure—I might say additional pressure—on the trap, we cut that to something like 75 ft. per sec. and cut the production some 10 bbl. per hr. without changing the intake pressure.

It is rather difficult to explain that situation on a matter of velocities, so we need a method whereby we can determine bottom-hole pressures.

We have been told several times during the meeting that it is desirable to apply a gas-lift before the well stops its natural flow. I agree with that entirely; it confirms all of our work on that line. We start the gas-lift before the well stops its natural flow and thereby we can maintain production better than we can by waiting until the well stops flowing and then running tubing and applying gas.

The question arises, when are we going to run the tubing? After studying the matter of velocities—we had one well making 3000 bbl. and from estimated pressures only and the volume of oil and volume of gas the well was making, we ran tubing into the well and increased the production 56 bbl. a day. We had another well making only 1400 bbl. and from the volume of gas, it was questionable whether we could benefit the well by running in tubing, but we felt there might be a chance to increase the production, so we ran the tubing and cut the production from 1400 to 1000 bbl. a day, but, by injecting a large volume of gas, we could increase it to 1400 bbl., but not above the amount it was producing naturally. Of course, we took out the tubing very shortly after that.

If we had an instrument which we could run into the hole while the well is flowing naturally, I think we could determine relatively closely the proper time to run in the tubing and make the well flow continuously. Also, I am quite sure that we could maintain a flatter production curve rather than have an intermission in production from the time the well stops flowing until we can move in the equipment and run the tubing. Sometimes this delay is a matter of 48 hr. or more.

We have been doing a little work on determining pressures at the bottom of the tubing by means of gas formulas and that again is a rather complicated problem. We have arrived at an answer. How near right it is I rather hesitate to say, but I believe we are coming close to it. We are using Weymouth's formula, but a different constant. That constant is based on specific gravity, among other things, and temperature, which we do not usually take into consideration. This study is apparently giving us some results which are interesting.

We are finding a rather narrow limit for our velocities. We calculated by this formula in what we consider our best installations, velocities from 7½ to 10 ft. per sec. When you can draw that down to within such narrow limits and feel you are reasonably right, I think you have made a very big step forward in determining what size tubing you are going to run and when you are going to run it.

We do not feel that we have the problem worked out by any means, and we feel we have made only a very, very small step in the right direction and reserve the privilege of changing our minds without notice.

The intermittent injection of gas has brought up another question. If we are to gain such great efficiency in our lift by means of this intermittent injection of gas it rather changes our original basic idea of the efficiency of the air or gas-lift.

When the air-gas lift was first coming into common use in the Mid-Continent there was a great deal of discussion as to the value of foot pieces for injecting the air into the column of oil for the purpose of increasing the efficiency of the air. We hear very little about that now. So far as I know, no one has any definite information on it, but very few now feel there is any particular advantage in that method. It certainly cannot enter into intermittent injection of the gas. There must be a

long column of gas and a long column of fluid, then another column of gas and another column of fluid, and so forth. It is practically solid fluid, and then solid gas, if you can say "solid gas."

That is rather a new idea, I think, in efficiency of the gas-lift. By getting the fluid only and then gas only, we gain much greater efficiency than when we introduced a continuous stream of gas which must have formed a much better mixture of oil and gas than there is under intermittent injection.

What are the possibilities of such a study? I think the subject has only been touched. At present it is no more than an idea, but it is so divergent from some of the original theories we held, I think it is important.

I believe our present work is leading us toward the flowing of smaller wells by means of the gas-lift. The gas-lift is running into competition, stronger competition all the time, with the plunger pump, because of its consistent operation, but we finally get down to the stage where if we are to use continuous flowing, a very large volume of gas is required to flow continuously. If we try to flow intermittently, we run across several problems. One is the high pressure required, just as in the case of a well flowing. Of course, we can run a small string tubing inside a larger string, but if we do that, we have a volume chamber in which the oil can collect and the time necessary to build up the pressure to remove the oil is much longer than required for the oil coming from the sand to fill up the volume chamber.

What can we do toward developing kick-off valves? We have kick-off valves of many designs, but none have been developed to the point that we feel they are entirely dependable. I think it will not be long until we have improved designs of the present valves on the market or perhaps something built on entirely different principles which we can use and which we can depend upon to give reliable results. Intermittent flowing is going to be in quite common usage, especially in deep wells, because as soon as we can get it down to an economic basis of lifting the oil by means of the gas-lift, it comes into very strong competition with the plunger pump and, as I said before, I think this competition will increase but new developments are going to make it economical to flow wells of smaller production.

H. H. Hill.—Do you believe that the ultimate recovery will be increased by using the gas-lift?

C. V. Millikan.—I know of no new data on that subject. I think everyone familiar with the results obtained with gas-lift is agreed that in almost all installations we do increase the ultimate recovery, but my strongest argument for it is the fact that almost without exception, when we apply the gas-lift to a well, we do reduce the natural gas-oil ratio; in fact, in some cases more than 50 per cent. reduction in natural gas-oil ratio occurs.

A. Knapp.—In starting a well that would ordinarily require a very large pressure to start it, is it not the practice to put the air first on the inside and then on the outside of the tubing, and by balancing it back and forth, get the well to flowing at the lower pressure, initial air pressure?

C. V. Millikan.—Some of the operators have tried that.

A. Knapp.—Is the phenomena of the intermittent flow after the well is started any different from what you would expect if you had continued that balancing? That is the way water wells are very often started. You have a compressor with 500 lb. maximum pressure and you can start a 1000-lb. well by balancing it back and forth. Is the phenomena any different than if you had continued to balance back and forth? You mentioned a 45-min. cycle, which would mean that there was no balancing back and forth of fluid.

C. V. Millikan.—It is continuous flowing all the time, but it may be flowing at the minimum of the cycle. It might be flowing 20 bbl. per hr. for an average production of 35 bbl. per hour.

A. Knapp.—The appearance of the flow at the top of the well would be no indication of a balancing back and forth of liquids at the bottom?

C. V. Millikan.—No; it is a continuous flowing. You might have a pulsating flow; we do in most of our wells.

A. Knapp.—But the phenomena accompanying the intermittent flow is quite different from anything you would expect from a balancing back and forth?

C. V. Millikan.—Oh, yes; each time you run it back and forth, you get a little more aëration.

A. Knapp.—That is a matter of inertia in the starting of the wells, but in intermittent flow do you not continue to use inertia to get the oil to the top by giving it a series of pushes?

C. V. Millikan.—Yes, you might consider it a matter of inertia. I think it is quite different from the balance case, though.

H. H. Hill.—As I get your point, Mr. Millikan, with intermittent flow, we get away from the ideas we formerly had of the necessity of aërating the column of fluid. You really have a slug of oil followed by a slug of gas rather than a continuous aërated column of fluid as is the case under the old system.

C. V. Millikan.—That is my theory. There may be some entirely different explanation, but those using the gas-lift seem to be sold on the theory of thorough nëration, and have it so imbedded in them that it is rather difficult to get away from it, but we surely have greater efficiency by separate volumes of gas. I am not willing to get clear away from that theory as yet, but see no better explanation at the present time.

H. H. Hill.—Do you have a means of determining at the well that you are actually getting a slug of gas and a slug of oil?

C. V. Millikan.—There is no question about it. This occurs in a great many cases in what you might call our steady flowing conditions, particularly in the wells at Seminole which had such low gas-oil ratios. We had cases of pulsating where a well might be making gas at the rate of 2,000,000 cu. ft. daily and over cycles of 1 min. or less that volume would increase from practically nothing up to a rate of 4,000,000 cu. ft. daily. In some instances where we are introducing gas continuously we get the same kind of pulsating flow.

Hydrogen Sulfide Corrosion in West Texas

R. S. Knappen,* Tulsa, Okla. (written discussion).—The corrosion situation in West Texas is very bad, but is, in all respects, similar to the corrosion problem which was encountered in Mexico and refineries handling Mexican and other sour crudes. The West Texas situation is worse, in one respect, than in any other place, because the percentage of hydrogen sulfide in the gas ranges up to 12 per cent. in some areas. On the other hand, the corrosion is less severe than in many places, because the climate is drier and several of the fields, as yet, are not producing important amounts of water.

---

* Gypsy Oil Co.

Our present information indicates that corrosion in West Texas is primarily conditioned by three factors; namely, hydrogen sulfide, water and air. No corrosion has been experienced in casing, tubing, separators, etc., where air and water were absent. Where air and hydrogen sulfide are present, without water in liquid form, there is little corrosion. For instance, the air-lift has been used in many wells which were not producing water without causing appreciable corrosion of tubing. On the other hand, a string of tubing was literally dissolved away within 50 days, where air-lift was used on a well producing considerable water as well as much hydrogen sulfide. Considerable corrosion results where water and hydrogen sulfide are present, but air is absent.

Applying these general statements to tanks, one would expect least corrosion of the tank sides where the oil stands. Considerable corrosion should be found on the bottom and sides up to the B. S. or emulsion line. The worst corrosion should appear on the inside of the roof and the sides above the oil where moisture from the air condenses and both gas and air are present. Experience shows that these expected results regularly appear in storage tanks.

The hydrogen sulfide corrosion may be prevented by (a) eliminating the hydrogen sulfide, (b) preventing air from entering the system, (c) eliminating water completely, or (d) by using protective coatings on exposed metal.

The elimination of hydrogen sulfide is impractical. The oil gives off this gas for some weeks after it has been run into the tanks. It could be removed by blowing pure gas or air through the oil, but evaporation loss and operating expense would, of course, be prohibitive. The elimination of water is partly possible by careful separation of water and oil, and by treatment of all cut oil to completely remove the water. However, condensation on the inside of the tank will slowly introduce water and promote corrosion, both at the top and the bottom of the tank. Air could be excluded from the tanks by using gas-tight roofs and maintaining a slight gas pressure inside the tank.

It would be necessary to connect the tanks with a source of gas in order to make up, during the cool part of the day, the gas which had been lost by breathing during the warmer period. So far as is known, no company has tried this system. It would be expensive and would necessitate very careful supervision. By keeping the tank nearly full of oil, the amount of breathing and, accordingly, the amount of air introduced into the tank can be considerably reduced.

Several companies are experimenting with a flexible, steel roof for their tanks. The tanks are nearly filled with oil, and when the gas above the oil expands the roof is supported by the gas. As the gas contracts, the roof subsides until finally it rests on the usual timber supports. Automatic valves are provided to prevent the pressure or vacuum inside the tank from exceeding safe figures. Theoretically, so long as the tank is nearly full of oil, the gas may expand and contract repeatedly without damage to the tank, and without admitting air or atmospheric water into the tank.

Protective coatings are easy to specify, but difficult to secure. The coating must be nonsoluble in oil, gasoline and water. It must resist attack by hydrogen sulfide and by air. It must be sufficiently elastic to permit the expansion and contraction of the tank steel. Many laboratory experiments have been made. So far, no satisfactory coating has been secured, although several are now being given large-scale tests on tanks. Pinholes in the coating and expansion cracks have caused much trouble on large-scale tests with varnishes, shellacs and similar materials. It is difficult in the laboratory to duplicate the field-service conditions.

In the wells little difficulty is experienced with corrosion except where the air-lift is used. This causes little trouble until water appears. Thereafter, it is impossible to use the air-lift without rapidly destroying the tubing. If the well is flowed through the casing, of course, the casing is also rapidly dissolved away. Several companies

have been using gas instead of air for blowing their wells. It is believed that if the gas could be secured entirely free from water it could be put through compressors and returned to the wells without difficulty. Where water is present, corrosion is severe in the intercooler, traps and high-pressure cylinder. One company has erected a Kopper's plant for purifying the gas. In this the gas bubbles through a solution of soda ash and the hydrogen sulfide is removed. The gas can then be compressed and recycled to blow the wells. By recycling, gasoline losses are avoided. The soda-ash solution with its hydrogen sulfide content is purified by the simple expedient of blowing air through the solution, which removes most of the hydrogen sulfide and oxidizes the remainder to harmless sodium thiosulphate.

Recent Developments in Water Flooding

J. B. Newby,* Bradford, Pa.—The most important forward step in the last year or two in water-flooding has been the realization that we have not known enough about our water intakes. The custom has always been to convert a well into a water intake and then let nature take care of it. The result has been that the information on water-flooding is a one-sided picture entirely confined to the production side of the record. It has not been known what work the intakes have been doing or what the correlation has been between pressure and input.

If a computation is made of the horsepower represented by the input of an average water intake at Bradford, the figure obtained is surprisingly low. An average satisfactory input is 40 to 50 bbl. per day. The average hydrostatic head is about 1500 ft. The horsepower represented is approximately 0.5 per min. This obviously suggests that the floods could be speeded up by increasing the pressure and with it the input. On the other hand, we are advised that theoretically, slow flooding is much more efficient than rapid flooding, and for that reason there is some question whether or not we should speed up the flood movement. Nevertheless, a number of the operators are preparing their properties, to introduce water from the surface, and in so doing, they will measure the quantity of the input. Other operators are metering the input by lowering small meters down into the wells at periodic intervals and measuring the rate at which water is going in. They also secure the level of the ground water and in that way get the effective pressure at the well.

Another step forward has been the emphasis laid on the variations in the rate of flood movement in different layers of the sand, the result of which eventually is that there are some layers not flooded out at the time oil wells are abandoned. Once better data are secured on our intakes, we can perhaps evolve different methods of flooding and get a more uniform flooding of the sand.

I presume in progress we should include not only data which are favorable to certain features but also data which are unfavorable or neutral. In the latter class is soda-flooding. The largest users of solutions in water-flooding are the Kendall Refining Co. who have introduced soda into some six properties. They have as yet received no returns that would justify the expense and many of the oil wells affected by the soda flood are nearing exhaustion. On the other hand, there has been no evidence of plugging of the sand, such as might result from precipitation by chemical action between the soda and calcium contained in the sand or in connate waters in the sand.

They have at one locality two groups of wells located close together in which the circumstances were quite similar. One pair of wells was affected only by water-flooding and the other pair was affected only by intakes into which a soda solution had been introduced.

---

* Vice-president, Petroleum Reclamation Co.

The production curves of these two groups of wells are quite illuminating. The normal production curve of a line water-flood well shows a rapid rise, a rather sharp peak, and a rapid decline until the production becomes a small percentage of the peak, roughly one-fourth to one-fifth, at which point the marked flattening begins.

The soda-flood wells showed a production curve in which the first pressure was felt some two months later than in the water-flood wells, the increase was a third to a quarter less, the peak was approximately a third less. The rate of decline was somewhat more gradual than in the water-flood wells, but the curves do not vary as much there as on the increase side. The flattening occurred on a higher plane.

On the other hand, the total production from either group of wells was about the same. In other words, no more oil was taken from the one than from the other.

Dr. Nutting, when advising that soda solution might be advantageous, described that very type of curve as what you should expect from soda-flooding. The exceptions to his forecast are that the rate of decline is actually more rapid than anticipated and the total production was not increased.

Two other features which have recently been realized as of some value in water-flooding are water analyses and detailed data of sand conditions. The first is a guide to the position of the flood and the second is an indicator of the total production to be secured.

One other feature should be mentioned. It is the five-spot development plan. This consists of laying the property off in squares, drilling a water well at the corner of each square and in the center drilling an oil well. In this way a four-way push to each oil well is developed. A tract in the center of the field has been partially flooded in this way. Drilling was started last September and production now is 200 bbl. a day. There was less than a barrel a day production previous to development. The oil-well to water-well distance is about 175 ft. which is comparable to the average line flood distance. Customarily it requires more than a year to reach large production in a line flood.

The property has produced around 1200 bbl. per acre within these few months, which is a total of over 12,000 bbl. and this has come from only nine wells. There will be a total of 20 drilled on the property.

As to ultimate recovery or net profits in five-spotting, the plan is to be considered as still in the experimental stage.

H. H. Hill.—I was very much interested in the results that have been obtained by using soda solutions because we have heard quite a lot about the use of soda in connection with water-flooding in the Bradford district. This latest development of using four water wells to one oil well I imagine is rather expensive, but as I understand it, you get quick returns.

J. B. Newby.—In this particular case they have secured quick results. The chance of greater profits lies in the decreased cost per acre of total development. It calls for a larger immediate investment, but a smaller total investment. There is also a large saving in operation costs in that probably a property will be depleted in four to six years whereas under the other type of flooding most of the operators have laid out their floods so as to deplete the properties in from 16 to 30 years. The saving in operation costs will be from 66 to 80 per cent.

C. V. Millikan.—Is there any change in the soda-ash content of the water reaching the oil well as compared to the amount contained in the water originally introduced?

J. B. Newby.—Yes, a marked change in that the soda is not present. In an oil well located only 82 ft. from an intake, a small quantity of soda ash showed for a few weeks, but in other wells no soda whatever has been found in the water. It is

apparently adsorbed, so possibly not sufficient soda has been introduced to give it a good test. However, in these particular cases the increased oil yield would have to be quite large if greater quantities of soda are used and a profit returned.

H. H. Hill.—What concentrations of soda are now being used?

J. B. Newby.—About 40 lb. per bbl. of solution.

Deposition and Removal of Paraffin from Oil Wells

F. M. Brewster,* Bradford, Pa. (written discussion).—The removal of paraffin from an oil well is a serious problem. Removing paraffin from the casing, tubing and well equipment is very expensive, but the costs can be calculated very closely.

Reistle[5] has outlined various tools and equipment for removing paraffin that have benefited the producer to a great extent. The widespread use of these special tools and methods has materially reduced the cost of operations.

However, the removal of paraffin from the face of the sand and from the pores of the sand is still in the experimental stage. The production lost due to paraffining of the sand is probably very great and results from a few wells that have been thoroughly cleaned indicate that the production lost is from two to four times as much as the oil produced.

Mills[6] has outlined very fully the troubles due to paraffin and suggested methods and processes for combatting them. These methods, such as the use of solvents, chemicals and mechanical appliances, have been used with fair success and give promise of further benefits.

Wood, Young and Buell[7] in their experiments with electric heaters found that in wells producing 30 bbl. or more per day there was no appreciable increase in production whereas in some of the smaller wells, increases varying from 50 per cent. to 800 per cent. were reported. This indicates that paraffining was confined to the tubing in the larger wells, but in the smaller wells the paraffin had deposited on the face of the sands.

A more comprehensive outline of conclusions appears in my paper on Handling Congealing Oil and Paraffin.[8]

---

* Petroleum Reclamation Co.

[5] C. E. Reistle, Jr.: Bur. Mines *Reports of Investigations*, Serial No. 2802 (April, 1927). Also A. I. M. E. *Tech. Pub.* No. 36.

[6] R. Van A. Mills: Bur. Mines *Reports of Investigations*, Serial No. 2550 (December, 1923).

[7] See page 262.

[8] See page 253.

REFINING TECHNOLOGY

Advances in Refinery Technology during 1927

By Walter Miller,* Ponca City, Okla.

(New York Meeting, February, 1928)

During no similar period in the development of petroleum refining technology has so much progress been made in methods and equipment for the economical utilization of heat. Drastically severe commercial and economical conditions controlling the refining industry during 1927 gave a great impetus to improved efficiency and more economical operation in all departments. I think it is fair to say, however, that more progress has been made in the department of heat utilization than in other branches. I use the word utilization advisedly in the dual sense of better primary generation and application of heat and of saving by recovery methods. It was because of this trend that the subject, "Economical Application of Heat," was made the keynote of the refinery engineering sessions just completed.

No new, outstanding elemental discoveries can be claimed for the year along this line. Some of the progress made has been in the development of better furnaces and distilling equipment embodying the more modern principles of boiler practice in obtaining complete combustion of the fuel, low excess air requirements and high transfer rates through the heating surface. Transfer rates of 3000 to 6000 B. t. u. per sq. ft. per hr. were considered good some time ago in the older type of equipment. Today a transfer rate of 25,000 to 35,000 B. t. u. is an actual accomplishment in commercial installations and engineers are talking of the feasibility of 50,000, 75,000, even 100,000 B. t. u. per sq. ft. per hr. Contributing most to bringing this about have been the rational use of the velocity factor on both the oil and firing side of the heating surface, and the study and application of the principles of radiant heat in furnace design.

Vapor Heat Economy

The principle of heat exchange, especially against oil vapors, has been applied to a greater extent than ever before. The recovery of heat from oil vapors is not new. This was practiced 20 years ago or more in Europe,

* Vice-president, in Charge of Refining, Marland Refining Co.

especially in centers where fuel was scarce and the incentive great. It was not, however, until the development of the modern tubular exchanger became a reality that vapor heat economizers made much headway in the United States. The inefficient, cumbersome and expensive equipment used in most of the few early installations did not pay sufficient return on the investment to justify extensive use, a high maintenance and repair cost also mitigating against a good commercial showing. Being in themselves modifications of the liquid-heat exchangers, these early units did not lend themselves to any startling results, temperatures of 100° to 150° F. being considered quite satisfactory. The exchangers of today, designed especially for the purpose of vapor to liquid-heat transfer, with thin wall tubes, the design providing for high velocity of both vapors and liquid, have made possible the recovery of a much greater proportion of the heat in the vapor. Oil temperatures of 250° to 500° F., with a possibility of still higher pre-heat, are actually being obtained by the proper coordination of vapor heat and residual heat exchangers.

Heat Removal

Another phase of progress in refining technology involving the same fundamental principles as the foregoing, but working in a diametrically opposite direction, is the economy resulting from improved methods of removing heat. Examples of this are the use of the thin-walled tubular exchanger as an auxiliary to the condensing apparatus, acting as a final after-cooler for the condensed liquids against the colder water. Another example is the use of the same type of equipment as preliminary coolers against solid water in refrigerating systems, and a third, the considerable extension of the practice of using the cold-processed refrigerated liquid to pre-cool the fresh oil to be refrigerated.

Nothing of a startling or revolutionary character seems to have been developed during the year in the realm of the purely processing side of refining. In the matter of fractionation, for illustration, some progress has been made in the further development of the use of side streams for bubble towers, and the production of heavy lubricating oil fractions by the single flash method. No notable improvement over the principle of bubble cap fractionation has been brought out, but the use of bubble towers has been greatly extended, and its superiority over other forms of ractionating towers more generally conceded. Worthwhile improvements in the design of bubble towers have been worked out; the construction has been so simplified that a substantial saving in metal, and consequently cost, has been effected. It is not felt, however, that the ultimate has been reached and it is conceivable that the fractionator of five years hence may be as far ahead of today's design as today's design is ahead of that of five years ago.

Gasoline Treatment

Some progress has been reported in the treatment of gasoline and gasoline-bearing fractions with sulfuric acid at low temperatures. This method was worked out and is in commercial use in California. It seems to be particularly advantageous in the treatment of cracked distillate from California crude products, which when treated by the ordinary method showed very excessive costs and unusually high losses. A great deal has been published during the year regarding the chemistry of and reactions involved in the chemical treating and sweetening of gasoline. This work will undoubtedly bear fruit in the future in the application of better methods, but today has not added much to the art in practical development, beyond the improved chemical control of the processes made possible by a more thorough understanding of the reactions. There has been a greater extension of the use of the vapor phase filtration method in the refining of cracked gasoline, and an improvement in the technique thereof whereby the yields per ton of clay have been increased to such an extent as to make the cost of fuller's earth a negligible factor. More interest is being displayed in this today than ever before, and it seems quite possible that the use of the process will extend more rapidly in the immediate future. It seems to be particularly valuable in the case of those cracking processes which produce a finished, fractionated gasoline, it being, apparently, the only method discovered so far giving a finished gasoline of good color, stable to sunlight, which does not require acid treating and consequent redistillation.

Sulfur Problems

The question of desulfurizing gasoline is confronting the refinery engineer today in a more acute form than ever before. The increased producing possibilities of the Permian Salt Basin area of West Texas, with a present daily production of 350,000 bbl., and an estimated potential production of 750,000, constitutes a serious problem for the future. A great deal of fundamental research as well as cut-and-try work has been done along this line, but so far with very little results of practical value. Some of the newer pools discovered in this area during the present year exaggerate the difficulty by the fact that the straight run gasoline contains much higher percentages of sulfur than that of the earlier pools, and the sulfur derivatives seem to resist removal to a greater extent. For a while there was some thought that the problems might be alleviated by raising the limit of sulfur tolerance in the official specifications for gasoline. This was quite a live topic during the year, but the result of considerable research and investigation work indicated that there was a real reason for the specification of not over 0.1 per cent., and that any lowering of the

bars would lead to excessive and costly deterioration of internal combustion engines.

Lubricating Oils

Although there has been no outstanding accomplishment in the manufacture of lubricating oils, steady progress had been made along several lines. A number of new plants have been installed, utilizing the contact process of filtration, and on the other hand several installations of the multiple hearth furnace have been made, insuring the more economical operation of the percolating filtration plants connected therewith. So far as I know, no progress have been made toward settling the standing question in contact filtration regarding the respective commercial values of the very expensive acid-treated clays versus raw, natural fuller's earth suitable for the purpose and found in many parts of the United States. Some progress has been made in distillation, such as the single flash bubble tower system referred to previously and the circulating pipe still which has proved of value in the Appalachian district.

Conditions in cracking are quite similar to those prevailing in the other branches of refining: while there has been considerable change in technique and improvement in operation, it has been the result of a steady advance in engineering and operating experience and knowledge rather than as the effect of any new process or even outstanding improvement in existing processes. The trend toward larger units of the established methods is quite pronounced. In some instances more than double the capacity of the previous standard size has been the aim of the newer, larger equipment. In many plants both the throughput and gasoline production of cracking units previously installed have been considerably increased by taking advantage of some of the new developments brought out during the year. Rearrangement of oil flow through cracking tubes, improvements in furnace design and combustion, a greater degree of perfection in some of the mechanical cleaners for coke chambers, improved knowledge of ideal temperature conditions and more desirable distribution of heat through tube banks have all played their part in this. The value of petroleum coke is becoming better known, and this as well as the fact that the cracking plants furnish a dependable source of suppy have been responsible for a considerable increase in the outlets, for this by-product.

Vapor Phase Cracking

Vapor phase cracking has received more attention during 1927 than ever before, the revival of interest in this method of producing gasoline synthetically having been stimulated as the high anti-knock value of the product became more generally recognized. Very little commercial use has as yet been made of vapor phase cracking, and it is quite certain that under ordinary conditions it is not yet commercially practicable even

if the resulting gasoline is sold at a considerable premium. A development of considerable interest in this respect was the announcement during the latter part of the year that two of the largest independent oil companies had pooled all the patents owned or controlled by them covering vapor phase cracking, and there is much conjecture as to whether, in the event that the method becomes commercially feasible in the future, a patent situation analagous to that existing in the pressure-cracking process field will arise. Such a situation would undoubtedly act as a deterring factor to the widespread use of these processes.

Anti-knock Compounds

The active advertising campaign in connection with the most successful anti-knock dope, and the resulting search for natural or synthetic gasoline of equal value has had the most important effect in the increased interest in vapor phase cracking. However, in the minds of some refinery engineers commercial success of the chemical dope in question constitutes a considerable hazard to those proposing to install the vapor phase type of commercial cracking unit. It is quite conceivable that if the cost of such synthetic gasoline remains materially higher than that obtained by the pressure cracking processes, installations of the same might easily be rendered commercially unprofitable at some time in the future if the premium charged for doped gasoline were to be substantially reduced as the result of lower cost of manufacture of the dope, consequent upon the larger quantities which will undoubtedly be manufactured as the use of the dope becomes more general.

Corrosion Control

Work in the field of corrosion prevention or control is being carried on in a more intensive way than ever before. The temporary corrosion committee of the American Petroleum Institute which crystallized at the December meeting into a permanent committee, has done much and will do much more in the immediate future to develop the issue and gives hope for rapid and valuable returns. Three or four regional or subcommittees of the main American Petroleum Institute committee are being organized in the natural geographical divisions of the industry. Development along this line during the past year has not been great but it is felt that there has been a considerable gain in knowledge regarding the factors involved, some further progress in the production of non-corrosive alloys and protective coatings, and in general a much better ground work prepared for future progress. On the other hand, the need for such knowledge is much greater today, because of the tremendously larger quantities of the more corrosive crude oils being produced now.

The economic pressure which the low price returns from the finished products exerted upon the refiner has not only impelled him to greater efforts in the reduction of his processing costs but also stimulated much greater activity and concentration along the line of conservation of waste and losses. As a result we have a more extended use of floating roofs, insulated tank tops, storage gas systems such as breather bags or gas holders, and pressure storage tanks for the reduction of the waste of light products by evaporation. A new development along this line was the announcement of a flexible roof tank, which created much interest and which may prove of great value in the field of long-time crude storage.

The introduction of the vapor-tight super-centrifuge machine is proving of value in the decreasing of naphtha losses in the manufacture of bright stock. Greater attention to tail gas recovery systems and distillation has resulted in some savings there.

There has been a substantial increase in the knowledge of the fundamental principles and reactions involved in refining processes. I have already mentioned the extensive work on desulfurization and sweetening of gasoline. There have been similar contributions on every phase of the industry. Leslie and Goode have furnished valuable information on the single and multiple flash distillation of petroleum. There has been valuable new information published on the physical and thermodynamic data of petroleum products.

Unusual progress has been made in the theoretical considerations of heat flow through thin tubes as well as in the actual application of such principles, and in addition an impetus has been gained along this line which augurs well for future progress.

DISCUSSION

R. E. Wilson,* Whiting, Ind.—There are a few additional points that might have been mentioned with regard to progress toward a better understanding of the true significance of some of the tests which we apply to gasoline and lubricants. Mr. Miller mentioned one point, the sulfur content of gasoline, which has been an issue for a number of years and which seems to have been agreed upon so far as present-day automobiles are concerned. I think we have also made during the year real progress in a better appreciation of the true significance of the distillation curve of gasoline, due to the work of the Bureau of Standards, financed by the American Petroleum Institute and the National Automobile Chamber of Commerce, with the cooperation of the Society of Automotive Engineers. That work has shown quite conclusively that it is not the initial boiling point of gasoline, but the point at which 10 or 15 per cent. is off, which determines the ease of starting in cold weather, and also that it is not the end point but it is the 85 or 90 per cent. point of the distillation curve which determines the completeness of vaporization and the ease of obtaining proper distribution in the manifold.

Work has not been quite completed on the intermediate point, but it rather appears that the 50 per cent. point, as well as the initial and end points have little significance and we can concentrate on these other two points on the distillation curve.

* Standard Oil Co. (Ind.).

The whole problem of anti-knock testing is gradually working its way out of chaos, and there is considerably better agreement today than there was a year ago between the different laboratories. There is as yet no standard method and those in closest touch with the situation feel it is still too early to standardize on any one method, but where we had a wide variety of methods, many of them indirect, which were considered in various quarters as being the best to tell the character of anti-knock gasoline, it has come down quite definitely to engine tests under fairly definite conditions, though different types of engines are still employed. So that by and large, when a responsible company says that its gasoline meets a certain anti-knock standard, it can generally be verified by actual test. This is in contrast to the situation a year or so ago. Of course there is still room for improvement.

There have been several papers published on the practical significance of the Conradson carbon test for motor oil, it having been shown that while the carbon deposit in a given engine was by no means directly proportional to the carbon residue, it did show a trend in that direction. It also appears that Conradson carbon does not have a direct bearing on the formation of certain gummy deposits which are sometimes found in automobile engines.

The moot question as to the importance of pour tests versus low temperature viscosity has been pretty well cleared up. I think it is now well agreed that while the pour test is important in insuring circulation of the oil through the lubricating system of the automobile, it has little bearing on the ease of starting; in fact, frequently oils of fairly high pour test will start easier at zero than the typical low pour test oils which have a high molasses-like viscosity at the lower temperatures.

The year has also seen the fairly general use in certain territory of the first prediluted or equilibrium type of motor oil. The first year this was on the market, about 9,000,000 gal. was marketed.

E. DeGolyer,* New York, N. Y.—Does the handling of the sulfur oils from West Texas require the development of a new technique over that which was built up in the handling of the high sulfur oils from Mexico?

Between West Texas oils today with a market price of around 60 c. at wellhead and the so-called sweet oils, such as the Seminole, there is a spread of about 70 c. in market price. This is a big spread. I should like to know what difference there is in refining value. Refiners are in a position, by quantity throughput, to accomplish quite a lot with relatively small amounts of money; a very few cents a barrel would pay for quite a lot of treatment which might be necessary to handle the sulfur oil.

W. Miller.—My personal experience has been confined to the Panhandle oils and my knowledge of the other crudes has been gained by comparing laboratory tests and also comparing my experiences with those of other refiners. The Mexican crudes that Mr. DeGolyer speaks of had as high as 2½ and 3 per cent. sulfur in some instances. However, research work carried on for the past two years, part of it under the auspices of the American Petroleum Institute research program, has shown that there are between 20 and 30 different kinds of sulfur derivatives in crude petroleums. Some of them break up under conditions of low temperature, others under conditions of high temperature, while some do not seem to break up at all and seem very hard to remove. Sulfur in petroleum has two disadvantages; one, the increase in refining cost due to corrosion of equipment which is a serious one in most crudes running materially more than 0.25 per cent. sulfur. The other is increase in the cost of refining the products themselves to the finishing point, in many cases it being necessary to adopt drastic chemical measures to remove the excess sulfur present. In the case of Panhandle crude, about a year and a half ago I estimated that the

* President, Amerada Petroleum Corpn.

extra corrosion cost and the extra refining cost on a barrel of Panhandle crude was 20 c. higher than if it had been the normal, average Mid-Continent sweet crude. Some of you may remember the figure of 25 c., but the extra nickel was lower value due to lower content of gasoline than normal Mid-Continent crude of that gravity would have shown.

Some of the West Texas field crudes will show lower corrosion difficulties than Panhandle; some will show higher, but they all seem to present to a greater degree the difficulty of a high percentage of sulfur in the gasoline, to some extent also kerosene, although that is not quite so vital.

The refining industry will be confronted with that problem. No way has yet been developed to take cheaply and easily that excess sulfur out of gasoline, and, as I stated before, there is less tendency today than there was a year ago to believe that we could raise the limits.

The quantities of the West Texas crude refined so far have been low enough so that we have been able to blend off the high sulfur gasoline with low sulfur gasoline from other crudes, but I think this will have an effect on the selling price of the crude oil.

I am quite sure of the figures on the Panhandle because I have checked those since with a number of other refineries which between them have run millions of barrels since I made the estimate and they agree that the figure is, if anything, conservative.

R. E. Wilson.—In the first place, in regard to the Mexican crude, the term refining of Mexican crude is to a great extent a misnomer. It has passed through the refinery as rapidly as possible with a little skimming and very little cracking, and if you are content to do that to West Texas crude, of course, you would have to figure on fuel oil values, or values like that of Mexican crude. However, if you get into cracking and get to the temperature at which these sulfur compounds decompose, you get many additional costs. The additional costs are particularly large in refining the cracked gasoline, because the best method for removing sulfur also removes certain constituents of cracked gasoline, and it is rather hard to get one out without destroying the other.

Of course, lower yields of high quality finished products are a serious handicap to any crude. In general there is a larger fuel oil residue or coke residue from the West Texas crude than from the Mid-Continent crude. Another important point is the considerable effect that the greater distance from the refining centers and the lack of pipe lines have on depressing the value of West Texas crude. While the price difference in the fields sounds large, if you compare the prices of the two delivered in Chicago, you will find that the difference in the delivered price is not far from the difference that Mr. Miller has mentioned as difference in cost of refining.

G. Egloff,* Chicago, Ill.—What are we going to do with the high sulfur crudes that are being found in ever-increasing quantities? The differential in price between the West Texas crudes that may run from 1½ to 2½ per cent. sulfur and Seminole is 90 c. a barrel, I believe West Texas crude is a very cheap oil that could be cracked, if market conditions were right for gasoline, into a handsome profit above that of Seminole. The equipment necessary to handle the high sulfur crudes in the refinery has, in my opinion, been largely solved not only for Mexican crude high in sulfur, but also for California, which has been age-old in sulfur corrosion difficulties.

In California they have solved the problem as far as one portion of the system is concerned, and that is the reaction chambers which may be 10 ft. dia. and 40 ft. high and chromium-plated. One report showed that a plant was operated on Cali-

* Director of Research, Universal Oil Products Co.

fornia crudes a matter of two years as far as the reaction chamber was concerned, and this portion of the system has shown practically no corrosion. However, the heating units cause difficulty because so far they have not been successful in chromium-plating them, and they corrode away after treating from 75,000 to 90,000 bbl. when the upper banks of tubes are replaced.

So these relatively low-grade, high sulfur content crudes, yield 40 or 50 per cent. of cracked gasoline containing from, say, 0.4 per cent. to as high as 1 per cent. sulfur. West Texas crude when commercially cracked will yield a high anti-knock gasoline.

Our gasoline specifications worked out in the dim and misty past call for 0.1 per cent. sulfur. In my opinion, that is far too low, and I have studied the literature on the matter, the work of Monzey, of General Motors, Diggs, of the Standard (Indiana), and they in all their tests prove conclusively that for about 9 months of the year, regardless of the sulfur content of gasoline, there is no corrosion, and the only corrosion takes place in, say, zero weather, or in cars that just run a short distance, shut down and start up, or run in the morning and in the evening; then they have a little corrosion in very cold weather. My understanding is that south of the Mason-Dixon line they have no motor corrosion problems whatsoever, regardless of the sulfur content of gasoline. Hence, I believe the specifications are too low. Companies I have known have marketed, without difficulties or kicks, gasoline from 0.3 to as high as 0.7 per cent. sulfur in gasoline.

If we can operate motor cars during warm weather where there is no condensation of moisture in the crankcase to take up the sulfur trioxide so as to form sulfuric acid, it is certainly idiotic to refine gasoline to 0.1 per cent. when the motor does not call for it. We estimate about a $50,000,000 refining loss a year to bring down the sulfur content to this 0.1 per cent. sulfur covering a 12-month period, when we could do away with it for a period of 9 months at least. The new motor cars with their ventilating systems are such that you can run on practically pure carbon disulfide, which is about 80 per cent. sulfur, without any corrosion difficulties practically.

Chapter IX. Distillation Methods

The Modern Pipe Still

By H. S. Bell,* New York, N. Y.

(New York Meeting, February, 1928)

It seems unnecessary to dwell upon the advantages of the modern pipe still as compared with the older type of distillation equipment used by oil refiners. The relatively low installation cost, coupled with remarkable operating efficiencies of pipe stills, precludes the consideration of other types except in rare instances where some peculiarity of product or plant may have an influence.

The question of the actual heat required to distil petroleum is quite involved. We have extensive data on the latent heats of the various hydrocarbons under different conditions of pressure. We also have information regarding the specific heats of various oils and the effect of temperature thereon. Because of the complexity of petroleum and of each fraction, it seems impossible to analyze theoretically the partial-pressure effect of the great number of hydrocarbons upon one another during distillation.

If a distillation curve and percentage analysis of any crude or product are available, it is possible to construct a curve with ordinates representing per cent. distilled and B. t. u. per pound or per gallon, or other desired unit. To do so the crude is split into fractions, of 5 or 10 per cent. The boiling point and gravity of each fraction being determined, it is possible to evaluate the heat required. As each fraction is removed, the residue must be raised to a higher temperature and latent heat supplied for the successive fraction. As the calculations progress, the latent heats decrease while the specific heats increase. Such a curve is illustrated by Fig. 1 for a typical 39.9° Bé. North Texas crude.

The chart is illustrative of batch distillation. Theoretically, if the oil were heated by a single flash in a pipe still, the partial-pressure effect of the light products would result in the removal of the same amount of vapors at a lower temperature. Practically, we find that because of the necessarily extensive fractionating equipment required when separating many products all in vapor phase, the oil has to enter the separator at temperatures corresponding to or even above those required in the batch still. Furthermore, in single-flash distillation the vapors evolved in the heater must be superheated to the outlet temperature. Very little is

* Consulting petroleum engineer.

known concerning the specific heat of the vapors, and the theory is complicated by the constantly changing pressure in the heater. In the calculation of the heat input, it is believed that this method (illustrated by Fig. 1) is sufficiently accurate until further data from research are available.

The efficiency of heat transfer is dependent on the velocities of the two exchanging mediums. Oil is a relatively poor conductor of heat and convection currents in large bodies of oil are very sluggish. Consequently, we find that in the case of shell stills, oil will not absorb more than 3 to 4 B. t. u. per square foot per hour per degree difference between flue gas and liquid unless some means of forced circulation is employed.

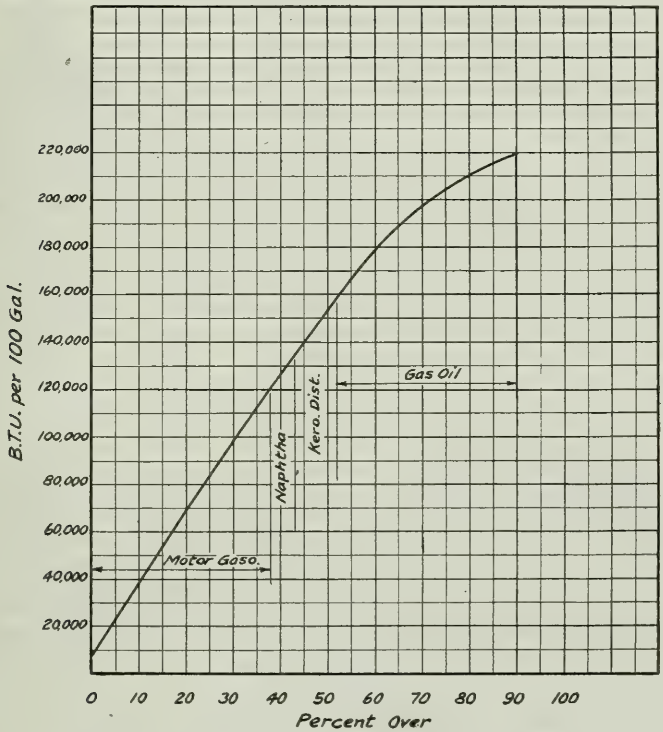


FIG. 1.—HEAT OF DISTILLATION (DRY) 39.9° Bé. NORTH TEXAS CRUDE.

If more heat is supplied to the plate than the oil can absorb, scorching of the oil and burned still bottoms result. Analysis of the heat input into oil passing through tubes at high velocity shows that 12 to 14 B. t. u. per hour can be safely transferred for each square foot per degree temperature difference.

For efficient transfer of heat we must have counterflow of the exchanging mediums. This cannot be accomplished in batch stills but is a feature of the well-designed pipe heater.

To avoid hot spots on a conventional still-bottom furnace, temperatures are rarely allowed to exceed 1600° to 1800° F. The usual practice has been to dilute the furnace gases with excess air at sacrifice of furnace efficiencies. Higher furnace temperatures are possible in pipe stills. The velocity and intimate contact of the hot flue gases are essential to input of heat to the steel surface, and here again, the tube still lends itself to efficient design.

Phenomena of Flow

We are familiar with the two phenomena of fluid flow in pipes. First, streamline flow, where the fluid may be considered as a number of con-

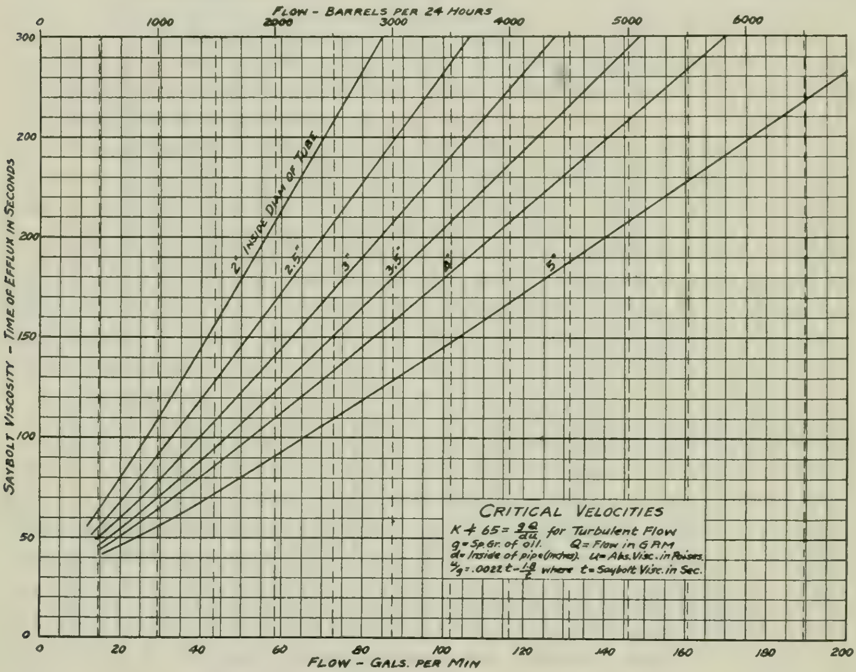


Fig. 2.—Minimum quantity of oil to insure turbulent flow.

centric cylinders each sliding past its neighbors; that next to the wall of the conduit has the slowest motion; the center one has the fastest. As increments of pressure are applied, the velocities are increased until a point is reached where further increments of pressure produce no increase of velocity. With further increases of pressure, a second point is reached when a further increment again raises the velocity. The fluid has now reached the second phenomenon of flow, called "turbulent."

Obviously, under the first conditions the outer cylinders of the fluid passing through a heater are raised in temperature above the average of

the fluid, and local overheating is probable. When the flow is turbulent, the fluid is rolling and eddying through the pipe and conveys heat from the wall to the body of the oil so that local overheating is avoided. Designers, therefore, endeavor to maintain turbulent flow throughout the coil.

The turbulence factor may be expressed by the formula

$$K = \frac{gQ}{du}$$

g = specific gravity	d = pipe diameter (inches)
Q = gallons per minute	u = absolute viscosity

If K exceeds a value of 65, the flow is turbulent. Viscosity decreases as the temperature rises; a decrease in viscosity increases the turbulence factor, so, obviously, if the oil in a pipe heater is in turbulent flow at the inlet, turbulence is assured all of the way through. Fig. 2 shows the minimum quantity of oil of different viscosities flowing through tubes of various diameters that will insure turbulent flow.

Assume a capacity of 2500 bbl. per day for a still of 4 in. O. D. No. 8 g. tubes, with an inlet temperature of 275° F.; at which temperature the oil has a viscosity of 40 sec. Saybolt. The flow at the inlet is turbulent. If 50 per cent. is to be vaporized, the outlet velocity will be in the neighborhood of 250 ft. per sec., or nearly 3 miles per min. With further vaporization, even higher velocities are met.

Pressure Drop through a Pipe Heater

On account of constantly changing temperatures, viscosities and gas volumes, it is impossible to predetermine theoretically the pressure drop through a pipe heater. The best forecast is empirical, based upon tests of similar heaters in service.

From the outlet of the pipe heater, the mixed oil and vapors are introduced to an evaporating chamber. Here we find a great many different types in service. Some are horizontal with longitudinal splash plates, some vertical with conical baffles. Others introduce the oil at a tangent in a vertical separator. Sometimes the stream is led directly into the fractionating column. All designs have some peculiar merit and meet to a greater or lesser degree the purpose. The evaporator should spread the oil out in a film to allow plenty of disengaging surface and be of a size to give sufficient time for separation.

Whether the evaporator is part of the column or is separate, we have at its outlet the same conditions; namely, a large volume of vapor composed of all of the overhead products. Upon their efficient separation into close commercial cuts depends the success of the distillation unit as a whole.

The bubble cap tower has superseded all other types for this service in connection with modern pipe stills. Here again we find a wide variation in design. In principle, the bubble tower may be likened to a series of small superimposed stills. Each plate receives heat from the ascending vapors. Through the intimate contact of vapors with the liquid on the plate, there is an interchange of heat and the heavy ends of the vapors are condensed into the liquid, while the light ends of the liquid are evaporated and ascend with the vapors to the tray above.

Books have been written on the subject of fractionation in bubble towers. It is beyond the scope of this paper to go into the theory in detail, but a few principles and conclusions should be kept in mind.

If there is no heat loss, and in a well-insulated column this loss is negligible, the liquid descending through the tower is supplied by returning a portion of the condensed vapors leaving at the top. If a column is supplied with a certain amount of heat at the base measured above a certain temperature, and there is no loss of heat, the sum of the heat in all streams leaving the tower will have to add up to the heat input. In the tower there is necessarily a drop in temperature as various fractions are condensed out. This sensible heat and the latent heats are abstracted by evaporation of the reflux fed into the top of the tower.

If perfect mixing were possible on each plate, the vapors ascending into the plate would be completely condensed into the liquid on the plate. This heat of condensation would evolve a new vapor, which would ascend to the plate above. Such a plate is termed the "ideal section" and is the basis of the theory of bubble columns.

The minimum amount of reflux for any given separation is attained only by an infinite number of ideal sections. This minimum reflux is a function of the concentration of light ends desired in the final product and the composition of the feed to the column. Since we can build neither an ideal plate nor a column with an infinite number of plates, some balance must be established between the amount of reflux and the number of plates. The lower the reflux ratio, the less heat will be required to effect the separation, but more plates must be used. If fuel is expensive, the column should have more plates and less reflux than would be the case with cheap fuel.

Since no plate is 100 per cent. efficient, it follows that the liquid on any tray is never completely stripped of the light boiling fractions found on the tray above. By means of multiple trays it is possible to make a commercial separation of a light product and a residue. If absolute separation of light products from residue is desired, it is necessary to redistil the residue. This may be done by the use of a separate column or stripping section, but in any case is dependent on the introduction of more heat. These facts illustrate the fallacy of attempting to bleed finished products directly from the tower. The means to effect the separation will be discussed later.

Theory of Separation in Relation to a Pipe Still

It is unnecessary to go into the theory of heat exchangers and condensers—both are important adjuncts of pipe-still units—but it is in order to discuss the preceding general theory as applied to the integral parts of a pipe still.

With reference to the furnace proper, it was stated that the pipe still is admirably adapted to counterflow of oil and flue gases. Therefore it is generally possible to bring the exit-gas temperatures down to as low a figure as will provide sufficient draft. With the usual heat-exchanging systems, inlet temperatures of 300° to 350° F. are encountered. Occasionally, more extensive application of heat exchange is made and temperatures up to 500° F. are on record. It should be pointed out that inlet temperatures around this figure begin to affect the furnace efficiency adversely. Since the over-all efficiency is the more important, a proper balance should be struck.

Correct furnace design is of prime importance to successful pipe-still operation. A surface will absorb heat from a radiating surface at about 10 times the rate of the absorption of heat by convection. Therefore the part of the pipe still doing the most work per square foot of surface is that exposed to direct radiation. The design of this section must carefully analyze the oil temperature and velocity to be sure that it will be able to absorb this heat. Otherwise, carbonization and burned tubes are inevitable.

It has been found that radiant heat and flame impingement on the same surface create a serious condition. By elimination of the flame impingement, higher furnace temperatures may be carried. The radiant tunnel construction is a development along this line.

Another line of approach toward the elimination of overheating is to keep furnace temperatures at a lower degree. The admission of excess air to accomplish this purpose is wasteful from all standpoints, but is the method still used in many plants. Recirculation of the flue gases will attain the results desired and at the same time maintain a high efficiency.

The mechanical side of furnace design is also important. The settings of a great many pipe stills are badly cracked by expansion strains. Air infiltration and consequent decrease of efficiency result. The suspension of the tubes by a structure independent of the furnace brickwork will eliminate much of this trouble.

Pipe Sizes

In the theoretical discussion of the flow of the oil through the tubes of a pipe still, it was pointed out that if the oil was above the critical velocity at the inlet there was no danger of streamline flow further on. In the

early days of pipe-still design, some units were built with tubes of 2-in. dia., and even smaller, with the idea of maintaining high velocities, but with such tubes trouble will ensue if the charging pump stops. Therefore, the practical consideration of ease of cleaning must be balanced against the desirable tube velocities. A small tube in a furnace of normal width at the usual temperatures will tend to bow and warp, thus adding to the inherent difficulty of cleaning the small bore. Therefore, we rarely find tubes of smaller diameter than 3 in. The usual sizes are 3 in. and 4 in. and if the use of such sizes results in too much pressure drop, it is considered good practice to use two or more tubes in parallel.

Bubble Towers

Bubble towers are available in a multitude of designs. Provided the number of caps and plates is sufficient for the separation desired, good results may be anticipated. The question of control is important. The inlet temperature at the base is capable of control by the heater. The top temperature will depend on the amount of reflux. Two general methods are used to furnish this reflux; first, using partial condensers, and second, pumping back a portion of the finished top product.

The results by both methods are the same, and the selection depends on practical considerations. If partial condensers are used, they must be placed so that the condensed product used for reflux will drain back to the tower. It is customary to use oil for cooling, thus making the partial condenser part of the exchanging system. The worst conditions, as far as corrosion is concerned, are usually found at the condensing point of products ranging from 180° to 250° F. This is just about the condition under which a partial condenser will operate so that relatively high maintenance may be expected.

On account of the added cost of steel structures to support the partial condensers, the difficulty and expense of repairs so high above ground and the disruption of operating conditions in the tower when such apparatus is out of commission, we find the trend away from such methods of control and towards the pump-in method.

Using a pump, the partial condenser becomes only a heat exchanger and may be set low. If the condenser is proportioned for emergency operation, the exchanger may fail and the tower will still function at the cost, of course, of some extra fuel.

Electric and air-actuated controllers are in use with both systems to control the top temperature.

The ideal tower control is one that gives a balanced condition of the reflux so that the tower temperature is held constant. With this condition, the result will be—theoretically at least—a maximum yield with the smallest amount of fuel for any particular installation.

Pyrometers and Air-actuated Controls

The problem, then, is to obtain a control instrument that will give this balanced condition. The sensitivity of the control mechanism will determine to a large extent whether or not the desired end points are obtained. There are two general classes of instruments which are being used satisfactorily: (1) pyrometer controls and (2) air-actuated controls.

Undoubtedly a pyrometer is more sensitive than any other type of temperature-measuring instrument. However, there must be a periodic make and break in a pyrometer temperature controller, and during the period that the thermocouple is disconnected from the motor-operated valve the reflux may become unbalanced, with the result that the tower temperature will not remain constant. From a practical point of view, the advantages of this type of instrument are that it may be located at any desired point without affecting its sensitivity, and the control may be set at the exact temperature at which the operator desires to control the tower.

The air-actuated controls fall into three classes, depending on the type of filling of the capillary tubes, each of which has its advantages and disadvantages. These three classes are: mercury-filled, vapor-tension and gas-filled instruments. As a class, the advantage is that as soon as the temperature is transmitted to the regulator, the reflux is brought into balance with the tower conditions. The controlling factors are the sensitivity of each type of instrument from a theoretical point of view, and the location of the instrument from a practical point of view.

It is claimed that the mercury-filled instrument is the most sensitive as well as the most rugged type. It requires short tubing lengths and therefore has the disadvantage of having to be located near the point of control.

The vapor-tension instrument is claimed to be as sensitive as the mercury-filled instrument, over a comparatively small range. The disadvantage is that it is necessarily limited to a smaller range of settings than the mercury-filled instrument; however, the length of tubing may be longer, so that the location of the instrument may be more variable than that of the mercury-filled controller.

The gas-filled instrument, according to instrument manufacturers, is not as sensitive as the mercury-filled or the vapor-tension instrument. It does, however, lend itself to greater flexibility from a practical standpoint, in that it may have as long a capillary tubing as the vapor-tension instrument and may be of the direct-set type operating equally well over a wide range of temperature settings.

When the tower temperature is to be regulated by air-actuated controls while pumping reflux into the tower, it is well to combine a pressure regulator with the temperature regulator in order that there may be a

fluid pressure ready to release the reflux liquid at the instant the control valve opens.

Although straight-line control is theoretically the most satisfactory, a variation of ±2.5° F. is well within reason for all practical purposes and may be accomplished with either pyrometer or air-actuated controls. The type of instrument to be installed can be determined only for the particular job under consideration; for example, if remote control is desired, the pyrometer controller is the most satisfactory; if simplicity of equipment is the outstanding need, the air-actuated controller should be installed.

Whether air-actuated or pyrometer controls are used, a by-pass line should be provided through which a certain amount of reflux may be passed continuously. Thus the control valve will be required to pass only the variable amount of reflux to take care of temperature changes.

Flow Sheet of Towers

The difficulty of obtaining side streams to specifications was previously discussed. It was shown that the overlap of distillation curves of

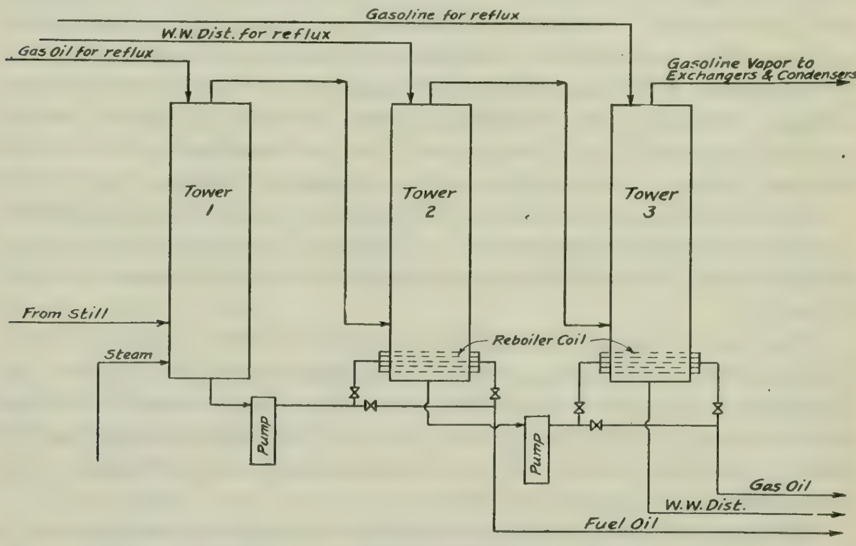


Fig. 3.—Multiple-towers 4-products.

adjacent plates was excessive. Effective separation is possible only between the top and bottom products of any one tower. This is in effect an argument in favor of multiple towers. Consider such an arrangement as shown by Fig. 3. Tower 1 effects a separation between fuel oil and all other products. The introduction of steam to lower the vapor pressure and hence create a reboiling effect is necessary on this tower, since there is no product hotter than the fuel oil to give up heat.

Gas oil, kerosene and gasoline vapors enter tower No. 2. Here only the gas oil is removed, the other two passing as vapor to tower No. 3 where final separation between kerosene and gasoline is made. In towers 2 and 3 there is available material at a higher temperature, the heat of which may be utilized for reboiling the material removed as liquid from the bottoms. The number of plates, tower diameter, etc., may be varied to meet conditions.

Now consider that one column will take the place of all three; assuming, of course, that the total number of plates will remain the same.

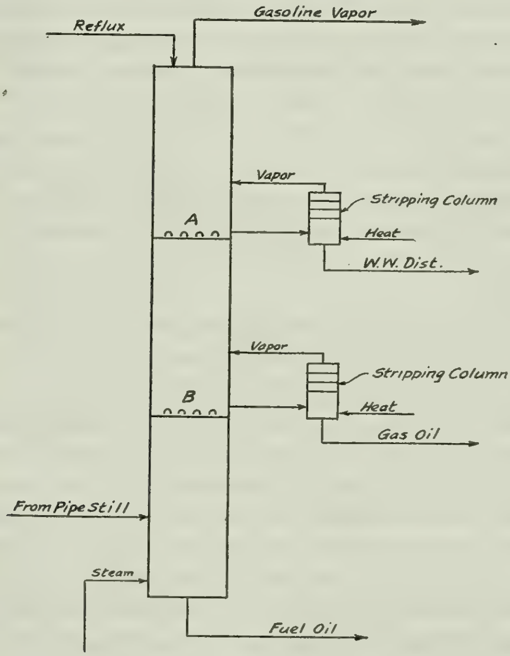


Fig. 4.—Single-tower 4-products.

Refer to Fig. 4. The overhead vapor cut will correspond to that from tower 3 of Fig. 3. At some plate *A* there will be a liquid whose highest boiling point will correspond to that desired for the end point of the kerosene. It will, however, contain light ends belonging to the gasoline series. Therefore it must be redistilled in a separate column with the application of heat from some source. The same is true of the gas-oil fraction. It would be equally possible to take liquid from a plate lower than *A* whose initial boiling point is at the end point of gasoline. This stream could be led to a side column and refractionated, so that the vapors evolved would form the kerosene cut, which would be led away and be condensed while the bottoms would reflux back to the main column.

It is unnecessary that these small auxiliary columns should be outside the main tower. Their function is accomplished by the various proprietary so-called "stripping" sections located sometimes within the tower itself. The efficiency of the tower, as far as absolute separation of products is concerned, is, however, dependent on the care and judgment used in the design of these sections.

Consider further the fact that the greater the difference in boiling points between two products, the easier is the separation in any given tower. For instance, the mean boiling point of gasoline, say, is 275° F., and of kerosene 490° F., a difference of 215° F. This separation is easier of accomplishment than that of kerosene from gas oil, with a mean boiling point around 600°F., and the difference only 110°. Likewise, the clean separation of gas oil from fuel oil is harder because the boiling points of these two products are still closer together. Therefore, as a general statement, the further we go into the crude the more difficult is the separation of successive cuts. Fortunately, very few refiners are interested in close cuts by boiling points after gasoline and kerosene are finely separated. The end point of kerosene is of little interest, if gravity and color are satisfactory. Of even less interest is the separation between gas oil and fuel oil.

When we come to the fractionation of the overhead products from a crude being run to cylinder stock, the separation of the heavy ends is of great importance. If any wax distillate or gas oil is left in the cylinder stock, the established flash, fire and viscosity relationships are altered, and the dewaxing problem is complicated. Likewise, the presence of cylinder stock in wax distillate is detrimental to wax removal by cold pressing. In the present state of the art, the more conservative method of effecting the final separation between wax distillate and stock is to remove only a portion of the distillate in the once-through pipe still and then use other apparatus. Batch stills or circulating pipe stills can be used. The series pipe still also appears to have possibilities.

Assembly into Complete System

In general, pipe stills may be divided into three distinct types: (1) the "once-through" or single-flash; (2) the series pipe still, where two or more are operated in series; (3) the circulating pipe still.

The first is the most popular and has the broadest field. With a properly designed single column or multiple towers, separations to meet specifications of all light products can be made with excellent yields and cost figures. For heavier products the separations are satisfactory as far as gas oil and fuel oil are concerned. It appears to have limitations when cylinder stock is the desired residual product.

The second type, in which two pipe stills are operated in series, presents two advantages. In this case, the volume of cuts removed in vapor phase is greater than in the case of the single-flash unit, therefore the possibilities of vapor heat exchange are greater. Secondly, if close separation of residuum from the next heaviest product is desired, a second simple tower will give better results. It will only have to separate two products, and the problem is not complicated by the partial vapor pressures of all the superheated light vapors passing through the tower. Fig. 5 is diagrammatic of such an arrangement.

It is said that such an arrangement is expensive to construct. As a matter of fact, careful estimates show that the savings in heat-exchanging equipment and smaller-diameter towers about offset the cost of two furnaces. Criticism has also been made of the high flue-gas temperature

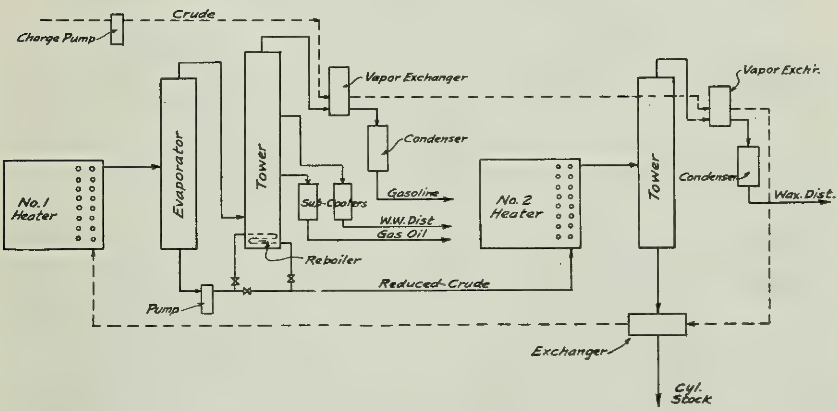


Fig. 5.—Series pipe still.

at the outlet of the second unit. This hot flue gas may be passed to the first unit and used to dilute the products of combustion at that point. Little has been done on commercial installations of this type, but it is believed that there are inherent advantages which should receive more attention. Particularly is this true where close control of bottom products is desired.

The circulating type of pipe still is in reality a batch still with an independent means of supplying the heat. While the addition of a circulating tube nest to a batch still will not in itself greatly improve the fuel efficiency of such a unit, it will eliminate the possibility of hot spots on the still bottom. As the oil increases in temperature, flue-gas temperatures must also rise, accounting for the poor efficiency as compared to the once-through or single-flash unit.

However, one advantage is inherent in any batch operation and that is close control of the residual product. To bring up the efficiency of

the circulating type of still, the diagram (patents pending) of Fig. 6 is submitted. This is in effect two batch stills, separators 1 and 2, connected to one pipe heater. Consider No. 1 as operating on the heater.

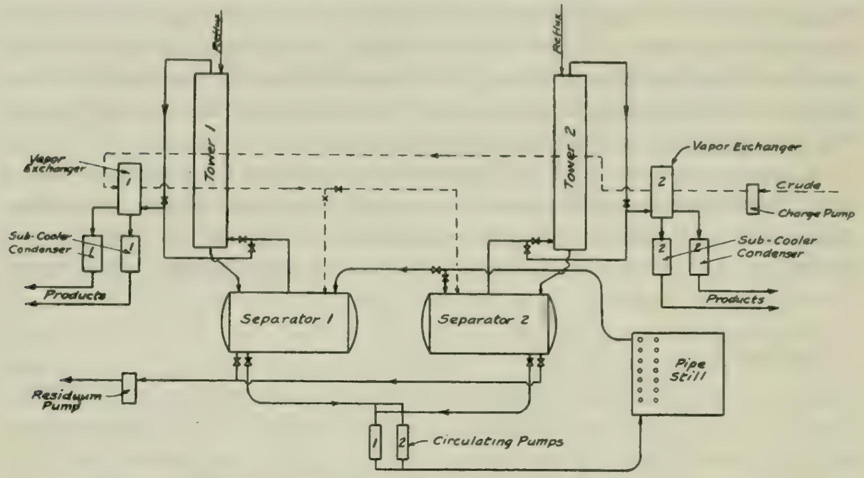


Fig. 6.—Duplex circulating pipe still. (Patents pending.)

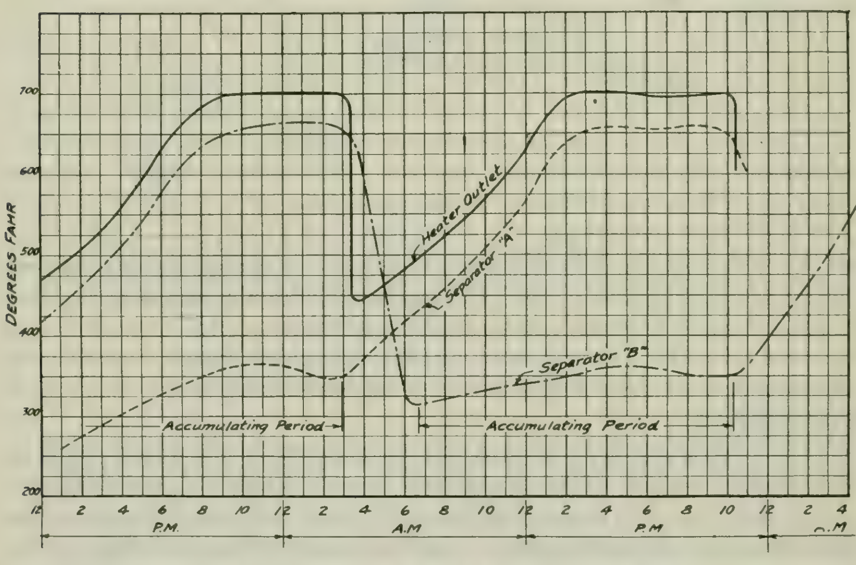


Fig. 7.—Temperature conditions for duplex circulating unit at Continental Refining Co., Oil City, Pa. Results of Aug. 13–14, 1927.

No. 2 may be used as an accumulator of heat by feeding the crude over the exchangers. By the time No. 1 is off, there is a batch of hot stripped crude in No. 2. The heater is then connected to No. 2 and No. 1 is

pumped out to serve as the accumulator for the next batch. The flow of crude on the next cycle is not shown on the diagram but is reversed in direction and goes into No. 1. The temperatures through two cycles from actual operation are shown by Fig. 7.

From actual runs, the fuel required for such a unit has been demonstrated to be between 10.5 and 11 lb. of coal per barrel, or about 2.4 per cent. oil equivalent when running Pennsylvania crude to cylinder stock. This compares quite well the efficiency of single-flash units.

The principal advantages of the arrangement are close control of bottoms coupled with good fractionation and over-all fuel efficiency. Its disadvantages are a higher steam consumption and limitations as to size. The maximum for one unit is about 1500 bbl. daily capacity.

Typical Examples and Results

Fig. 8 and Fig. 9 are a photograph and diagram, respectively, of No. 4 Foster still at the plant of the Marland Refining Co. It is of the single-flash multiple-tower type. The heater consists of a Power Specialty furnace with an effective length of 3334 ft. of 4-in. tube. Badger towers are used. The first, marked *A*, is a flash drum where the gasoline evolved in the exchangers is removed as an export cut having 350° to 400° F. end point. The temperature of the flash drum is determined by the amount of hot oil from the pipe still by-passed into the drum with the fresh crude. Tower *B* is an evaporator for the pipe still and *C* is the final fractionating column.

The crude circuit is first over the partial condensers, where it reaches a temperature of 220°. It then goes to a salt drum, from which it passes over residual exchangers and is raised to 250° before entering the flash tower *A*. Enough hot oil from the heater enters with the fresh crude to bring the temperature in the flash drum up to 370°. The oil is then pumped from the flash drum *A* through the tubes of the still, is raised to 550° and enters the evaporator.

The bottoms from tower *B* are pumped into a stripping section at the base of tower *C*, where they furnish heat for reboiling the bottoms from *C*. One top stream of gasoline and side streams of kerosene and gas oil are removed from *C*. This unit has a capacity of 7000 to 10,000 bbl. per day. Fig. 10 shows the distillation curves of products. When removing 75 per cent. of distillates from the crude, a fuel consumption of 1.4 per cent. is reported.

Fig. 11 is a photograph and Fig. 12 is a diagram of Foster still No. 5, also at the plant of the Marland Refining Co. This is also a single-flash unit with the fractionation accomplished in a single column. The furnace and tower are both of Power Specialty Co.'s design. The furnace is the same as that just described. The tower is 10 ft. 6 in. in diameter

and 76 ft. 6 in. high. This unit has a skimming capacity of 10,000 bbl. daily. When running to 11 per cent. cylinder stock bottoms, the capacity is reduced to 5000 bbl. and is intermediate for other proportions of overhead. The fuel consumption is 1.5 per cent. for 26.5 per cent. bottoms, and 2.4 per cent. for 11 per cent. cylinder stock bottoms.

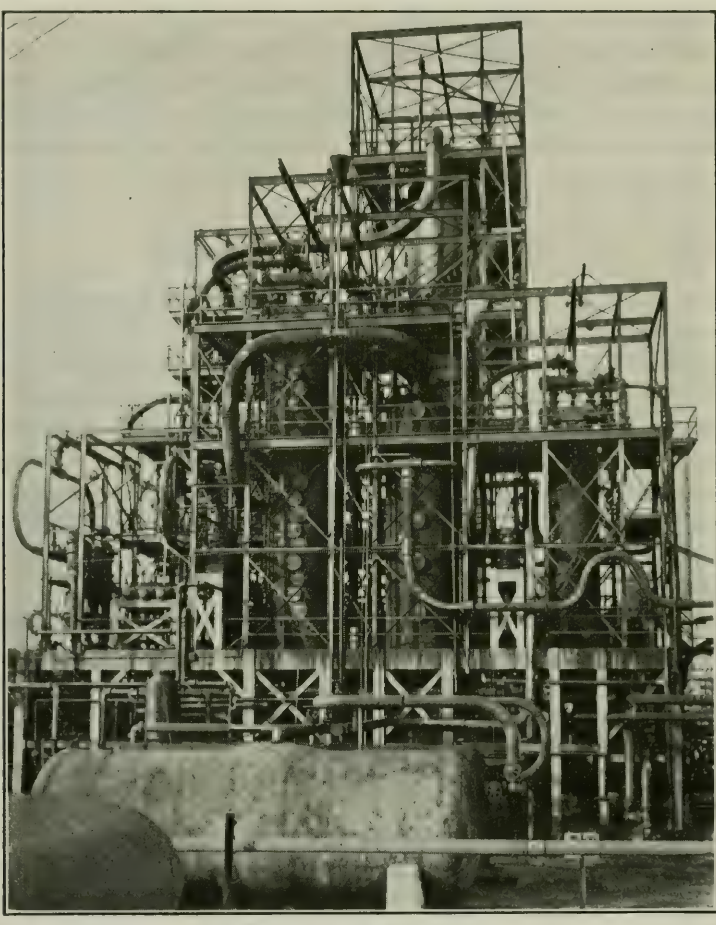


FIG. 8.—FOSTER STILL.

This gives arrangement of the three Badger towers. The small one on the right is *A* tower, where the first flash is made. The middle is *B* tower, where the second flash is made, and the one on the extreme left is the *C*, or bubble tower. The large tower back of *B* is the Power Specialty tower on No. 5 Foster still. All pumps and residuum exchangers are on the ground under the towers.

This tower is controlled entirely by the "pump-in" system, no partial condensers being used. When skimming, both finished gasoline and pressure distillate are used for reflux. When running to stock, finished

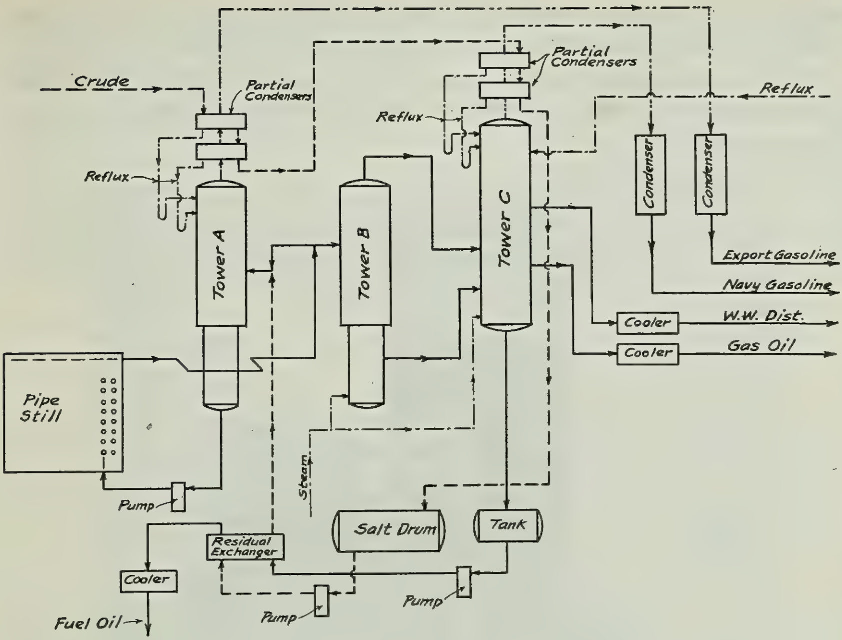


FIG. 9.—FLOW CHART, FOSTER STILL NO. 4, MARLAND REFINING CO.

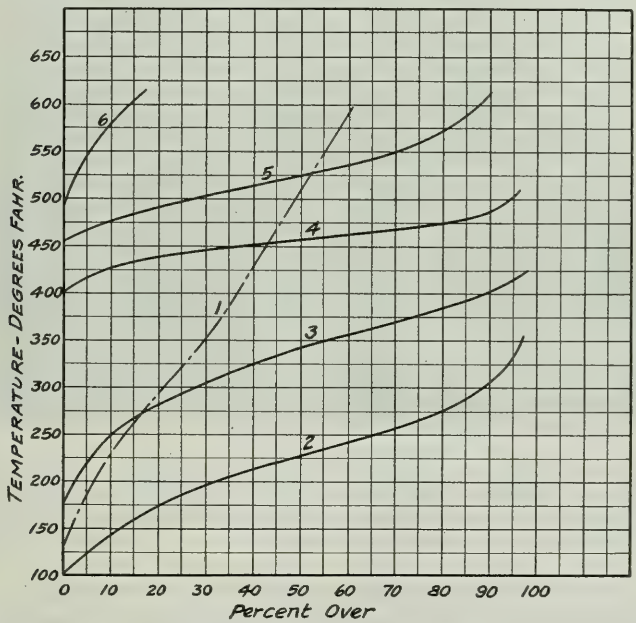


FIG. 10.—ENGLER DISTILLATIONS OF PRODUCTS, FOSTER STILL NO. 4, MARLAND REFINING CO.

1, crude, 39.9° Bé.; 2, overhead, tower *A*, export 64.5° Bé.; 3, overhead, tower *C*, Navy 53.5° Bé.; 4, kerosene distillate 41° Bé.; 5, gas oil, 36.7° Bé.; 6, residuum, 25.4° Bé.

gasoline only is used with a reflux ratio (gasoline returned to the tower divided by final amount of gasoline taken from the system) of 3.5.

In this tower the stripping sections are integral and the reboiling effect is accomplished by the use of steam. Fig. 13 shows the distillation curves of the products.

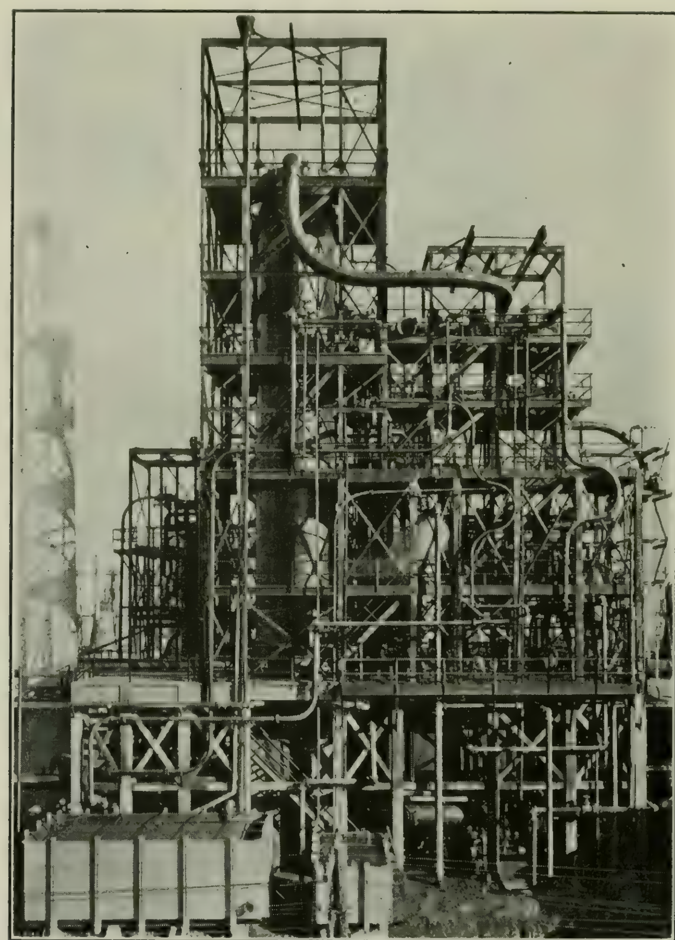


Fig. 11.—Foster still.

Shows the single large Power Specialty tower on No. 5 unit. Ground level has all pumps. First deck carries residuum and gas-oil exchangers and coolers. Second and third decks support gasoline and kerosene watercoolers. Fourth and fifth decks carry the vapor to crude exchangers and condensers.

A smaller unit with less refinement is shown by Fig. 14. This is installed at the plant of the Aetna Oil Service Co. at Louisville, Ky. It has a daily capacity of 2000 bbl. A Foster heater and towers of the writer's design are used. Results are shown by Fig. 15, which are the aver-

age for May, 1927. The fuel consumption over the same period, when running to 21 per cent. bottoms, was 2.15 per cent. and has been reduced somewhat since.

Fig. 16 is a photograph of a pipe still designed and built by the M. W. Kellogg Co. for the Simms Oil Co. at Smackover, Ark. The furnace is of the radiant-heat type, eight carborundum tunnels being used. The coil consists of 4-in. tubing with an effective surface of 6600 sq. ft. The unusually large amount of surface is accounted for by the purpose of the design, which called for the maximum gasoline yield from heavy Smack-

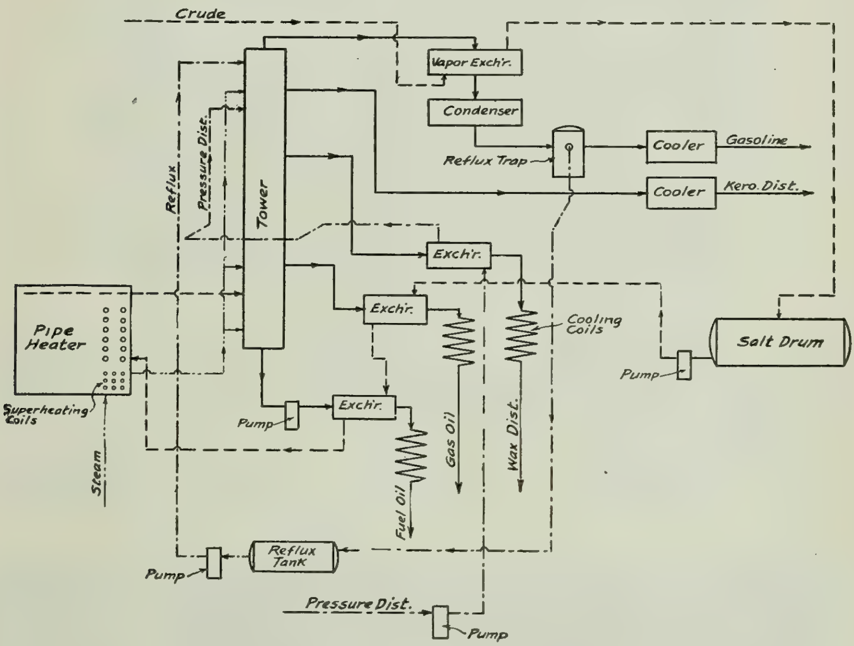


FIG. 12.—FLOW CHART, FOSTER STILL NO. 5, MARLAND REFINING CO.

over crude, coupled with bottoms that could be sold as commercial fuel. By operating under some back-pressure and utilizing some of the excess surface as a soaking section, the desired results are attained.

The unit has a daily capacity of 2500 bbl., removing 17 per cent. of gasoline and 47 per cent. of pressure-still charging stock.

Fig. 17 is a self-explanatory flow chart, the results being shown by Fig. 18.

An unusual pipe-still installation is shown diagrammatically by Fig. 19. This unit is one of two installed at the Petty's Island refinery of the Crew-Levick Co. In all other examples given, tower control is accomplished by either refluxing or pumping in a portion of the final overhead conden-

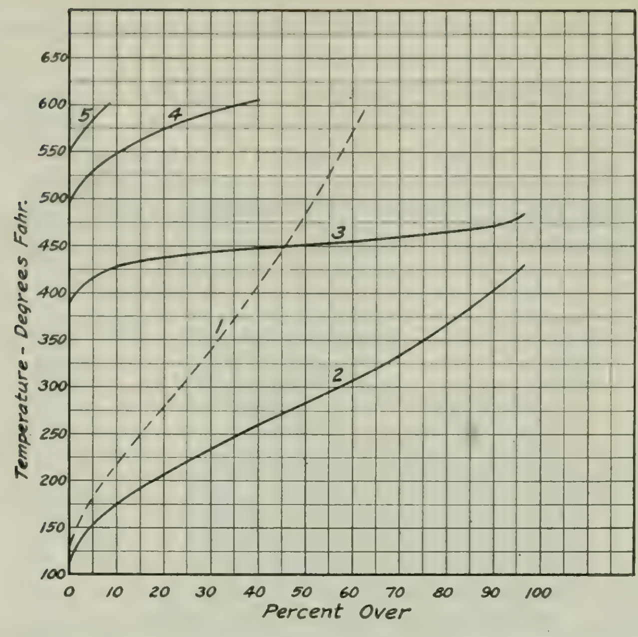


FIG. 13.—ENGLER DISTILLATIONS OF PRODUCTS, FOSTER STILL NO. 5, MARLAND REFINING CO.

1, crude 40.7° Bé.; 2, gasoline 58.2° Bé.; 3, kerosene distillate 41.5° Bé.; 4, gas oil, 35° Bé.; 5, residuum 24.5° B.

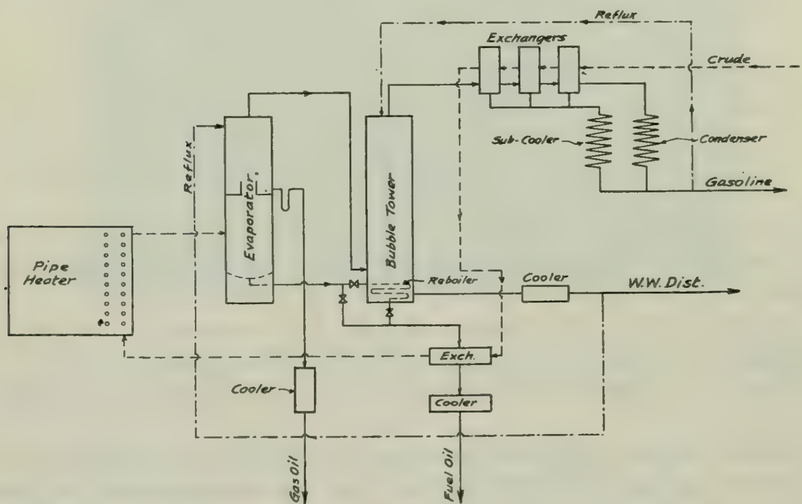


FIG. 14.—PIPE STILL (2000 BBL. PER DAY) AT AETNA OIL SERVICE CO.

sate. In this unit, the vapors of each tray are partially condensed and returned as reflux.

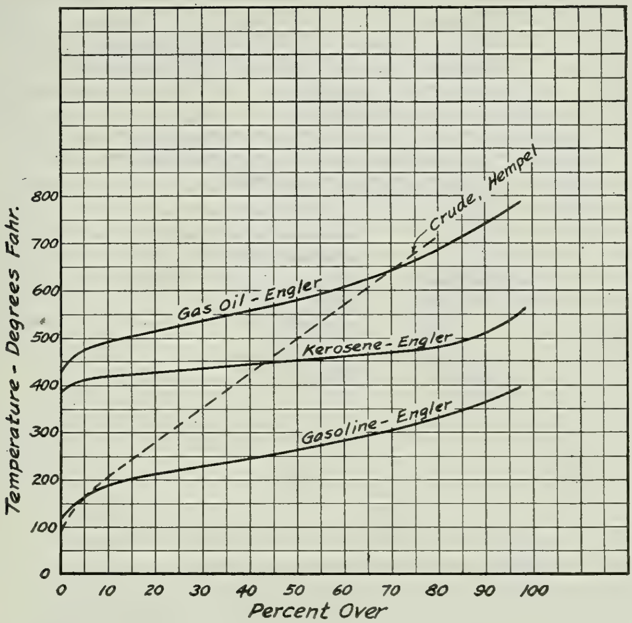


FIG. 15.—PIPE-STILL RESULTS FOR MAY, 1927, AETNA OIL SERVICE CO., LOUISVILLE, KY.

Yields: gasoline, 40.79 per cent.; kerosene, 6.77 per cent.; gas oil, 30.78 per cent.; 20/22 fuel oil, 21.03 per cent.; loss, 0.63 per cent.

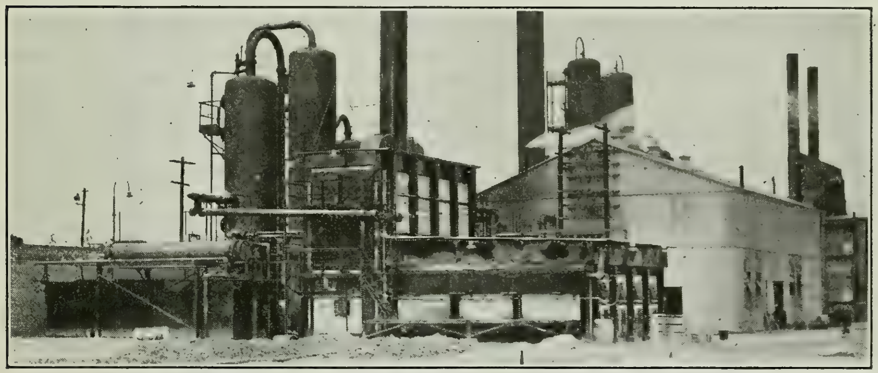


FIG. 16.—RADIANT-HEAT PIPE STILL (2500-BBL.) DESIGNED AND BUILT BY M. W. KELLOGG CO. FOR SIMMS OIL CO. AT SMACKOVER, ARK.

There are six bubble trays and six interchangers, one for each tray. The crude going to the unit is in the body of the interchangers around

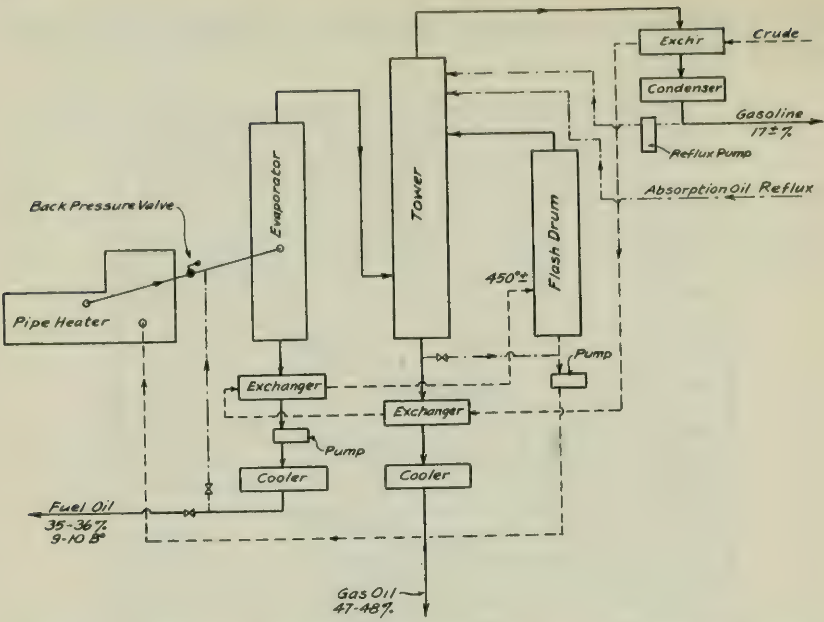


FIG. 17.—KELLOGG PIPE STILL OF SIMMS OIL CO. AT SMACKOVER, ARK.

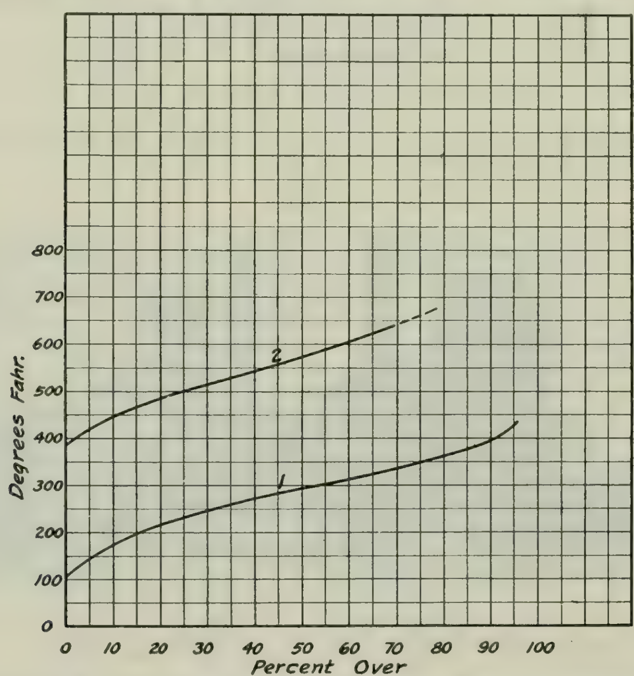


FIG. 18.—SIMMS OIL CO. PIPE-STILL RESULTS, SMACKOVER REFINERY.
Crude 20.4° Bé. Smackover; 1, gasoline, 53° Bé.; 2, gas oil, 27° Bé.; bottoms, 9.8° Bé., 585 furol at 122° Bé.

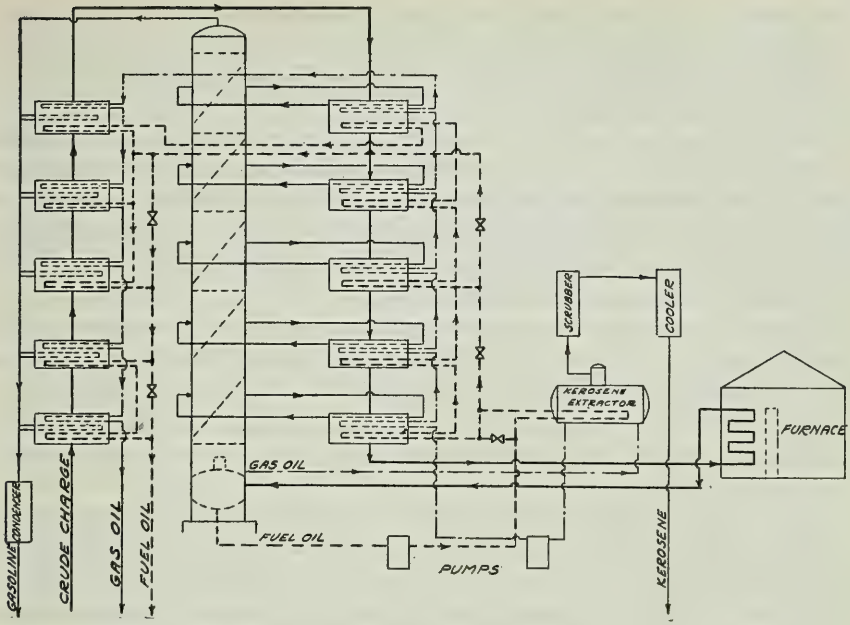


FIG. 19.—FLOW CHART, CREW-LEVICK CO.

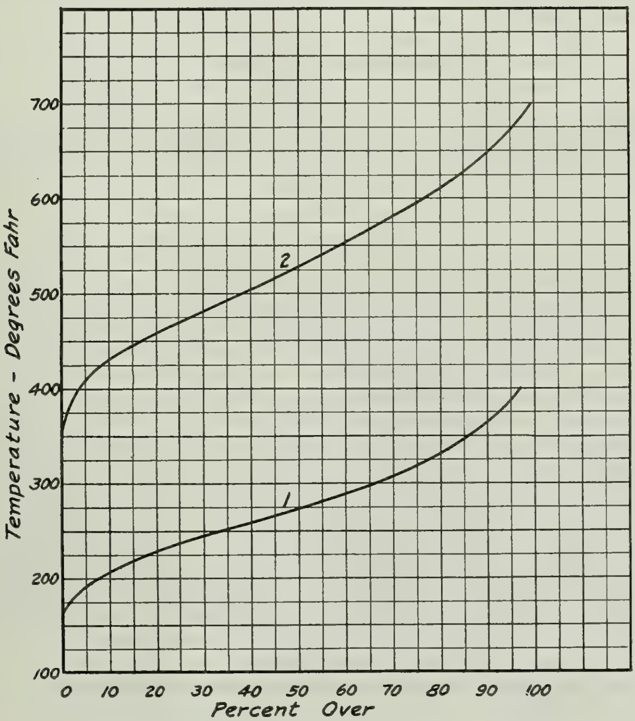


FIG. 20.—ENGLER DISTILLATIONS, CREW-LEVICK PIPE STILL. 1, OVERHEAD GASOLINE; 2, TOWER BOTTOMS (KEROSENE AND GAS OIL).

the tubes. The additional four interchangers are used only as heat exchangers. There are three sets of tubes in each of the 10 interchangers. Vapor is in one, hot gas oil in the second and hot residuum in the third. The principle of the design is to maintain a low temperature differential between the vapors from any one tray and the crude in the interchanger of that tray. The temperature of the crude is controlled by by-passes around the interchangers in the hot fuel-oil circuit. Thus the amount of reflux bled back to the tower is determined. Once the temperatures are established, a balanced condition is reached which requires very little attention. No automatic controls are used.

Note that only one overhead cut is taken from the tower. The bottom product is water-white distillate and gas oil combined. This is led to an auxiliary vessel, termed extractor. By means of open steam coupled with heat from the fuel oil from the evaporator section, the kerosene is removed. The gas-oil bottoms then enter the exchanging system as described above.

As might be expected from such a complete exchanging system, the crude enters the pipe still at a very high temperature, 500° to 510° F. being the usual figures. The pipe heater itself is, therefore, relatively small. The fuel consumption is exceptionally good, 1.4 per cent. being reported for an overhead of 60 per cent. The distillation curves of the products are shown by Fig. 20.

Acknowledgments

The author appreciates the coöperation of the Marland, Simms and Crew-Levick oil companies, without whose permission much of the data herein given could not have been released.

DISCUSSION

H. R. Swanson,* New York, N. Y. (written discussion).—A comparative analysis of pipe still design involves two major considerations: (*a*) simplicity of arrangement which insures smooth operation and, therefore, the maximum yield of specification products with a minimum of off-test material; (*b*) operating expense including fuel, process steam, labor, power, maintenance, etc.

In the first place Mr. Bell is skeptical of the practical realization of fuel economy as a result of single flash vaporization. Leslie and Goode demonstrate[1] quite clearly the several advantages of single flash vaporization as compared to successive flash vaporization. The single flash was found advantageous not only from the point of view of fuel economy but also as regards stripping the residuum of the lighter materials. These results were based on 50° steps in the case of the successive flash.

Of course the successive flash method, incorporating continuous pipe stills, is seldom found in practice to include more than three steps—the flash after heat

* Distillation Engineer, Foster Wheeler Corpn.

[1] E. H. Leslie and A. J. Goode: The Vaporization of Petroleum. *Jnl. Ind. Eng. Chem.* (Apr., 1927) 453.

exchange, followed by two pipe stills. However, it should be noted that very few pipe still units of this type reduce the crude below 15 to 20 per cent. bottoms. Removal of the light vapors in the first two flashes makes it impossible to reduce the ordinary crude below this point without excessive quantities of steam or by operating at a temperature which produces considerable cracking. The increase of the number of steps only adds to the difficulty until finally one approaches incremental vaporization in the case of a recirculating type of unit with a small temperature rise per pass.

Ashworth[2] presents the results of experimentation carried out in determining the temperature lowering effect of single flash vaporization as compared to normal laboratory flask or progressive distillation. The normal batch still parallels the laboratory flask as an example of progressive vaporization. A comparison of the liquid temperatures in the flask and pipe still for a high percentage vaporization readily indicates the futility of the batch operation and the advantage of the single flash when a low percentage bottoms is required with a minimum of steam.

The checking of several commercial units indicate the vaporization of from 8 to 10 per cent. more material for tube still final temperatures above 500° F., as compared to the vapor quantity shown by laboratory progressive distillation up to the same vapor temperature. If we then consider the difference of 70° to 80° F. between the liquid and vapor in the flask, we have some gage of the temperature advantage of the single flash operation as compared to progressive distillation, which is the most exaggerated possibility of the successive flash method. This temperature advantage becomes extremely important when reducing the ordinary Mid-Continent crude to the lowest possible residuum necessary in the production of overhead cylinder stock. The heat input as calculated is easily in favor of single flash vaporization. No directly comparable data are available on fuel consumption of commercial units with a check on total yield of overhead distillate.

Mr. Bell states that the extensive fractionating equipment required when separating many products, all in vapor phase, necessitates delivering the oil to the separator or tower at temperatures corresponding to, or even above, those required in the batch still. This conclusion might be drawn from the casual comparison of the single flash pipe still outlet temperature and the batch still final temperature, but the situation becomes quite different when the steam consumption of the two units is compared.

The steam used in the modern pipe still unit is for stripping the various liquid products of a small amount of light material and not primarily to assist in vaporization of the heavy ends. If the same amount of steam as is used in the normal batch or semi-continuous unit was used in a pipe still, and introduced into the tubes where vaporization takes place and latent heat can be added, we would find the final temperature of the single flash pipe still unit at least 75° below the normal batch still. However, in this connection fuel economy demands that we take advantage of one of the outstanding advantages of the pipe still—the very much reduced time element—permitting a higher final temperature than previously considered advisable, making possible the realization of a very much decreased steam consumption. In other words, given the same percentage of overhead vapor which could be delivered at a much lower final temperature with the same quantity of steam as the shell still, the solution of the problem of separation would be forthcoming even then, with less heat input.

Particularly in the case of a single flash unit there remains the decision between the single or multiple tower unit. The simplicity of arrangement and minimum necessary points of control incorporated in a single tower should be a readily recognized advantage. Furthermore, the extreme simplicity and ease of control of a

[2] A. A. Ashworth: A Pipe Still for Continuous Distillation in the Laboratory and Some Results Obtained from It. *Jnl.* Inst. Petr. Tech. (1927) **13,** 91.

single tower with the single point of latent heat removal with only two necessary points of control, should be obvious. The argument against the latter arrangement, as compared to the type used by the Crew-Levick Co., and illustrated by Fig. 19, is that the possibility of heat exchange is more advantageous in the case of the several partial condensers. It is very true that more heat can be recovered but some of this recovery is not realized because of a greater stack loss. Furthermore, from the standpoint of flexibility and capability of handling crudes with varying yields of products necessitating overdesign of each of the partial condensers, this unit would not appear to be low in first cost. Likewise, the smoothness of operation essential to maximum yield with a minimum of attention would appear questionable. Such a scheme would not be at all suitable in application to a unit running down to a low bottom and arranged for a pressable wax distillate stream which requires a particularly fine control to produce a maximum yield of consistently pressable product.

P. C. Keith,* New York, N. Y.—Authentic data on specific heats are available. We think those of Fortsch and Whitman particularly accurate, a straight line extrapolation of their data up to 860° F. having been checked by us within 5 per cent. Data on latent heats are much more meager, and any heat balance made from the oil side is open to question until further research reveals the true latent heats of petroleum fractions.

Referring to streamline and turbulent flow, I greatly doubt whether a heater has ever been built in which the flow was not turbulent. For instance, if a 36° Bé. Mid-Continent crude at a temperature of 300° F. fed to a pipe heater containing 10-gage, 4-in. O. D. tubes at the rate of 100 bbl. a day, the flow would be turbulent. If published temperature vs. viscosity data are correct the flow could be reduced to 60 bbl. a day and still be turbulent. This does not mean, however, that a pipe still would operate satisfactorily at such capacity. Turbulent flow affects carbon formation by minimizing overheating. Resistance to heat flow into the oil is approximately inversely proportional to the 0.8 power of the mass velocity. Hence heat transfer per square foot through the heater must vary. The optimum velocity having been previously fixed through balancing the increase in the inner film coefficient against the increased pumping costs, the heater should be designed so that no more heat enters the tube than can be absorbed and still maintain the oil film at a temperature below that at which coke deposition probably takes place.

Assume one wishes to heat oil in a cracking furnace to a temperature of 875° F. and to limit the film temperature to 900° F. to prevent carbon formation. Further assume an inner coefficient of 300, which with clean gas oil and a reasonable velocity, is easily obtainable. If the oil entered at 600° F. heat could be applied at the entrance at the rate of 90,000 B. t. u. per sq. ft. but at the exit the limit would be 7500 B. t. u. per sq. ft. In other words, a heater operating safely with the theoretical minimum surface would have its maximum load at the inlet and minimum at the outlet, maintaining an ever-decreasing temperature difference between the oil film and the main body of the oil. However, in practice this can scarcely be done. The heat input usually will be very low at the entrance in the convection section and increase to the maximum in the radiant section, and then begin to decrease as the final heating temperature is approached.

One method by which this can be done is to base the maximum heat pickup per square foot for the radiant section on the upper oil temperature limit of that section, and for economic reasons fix that limit somewhat under the final temperature, design the radiant section on this basis, then heat in another section of the furnace to the final outlet temperature. Such a procedure may mean slightly more tubing but

* Process Engineer, M. W. Kellogg Co.

it will result in a smooth running furnace with no danger of overheating. Practically, we favor about 20 per cent. heating in the convection section proper, 65 per cent. in the radiant and 15 per cent. in the last section.

Mr. Bell has stated that an over-all coefficient of 12 to 14 may be safely maintained. The temperature of the oil in the furnace, its velocity, the furnace temperature, and the maximum allowable film temperature must all be considered. In some portions of the furnace a much higher rate may be maintained and in others lower. However, if the figure is used as over all for the whole furnace and results in a gross over-all transfer rate of say 7000 to 9000 B. t. u. it is probably safe for most pipe still work. Furnace temperatures above 1800° F. are unwise unless high maintenance cost is of no importance.

Mr. Bell's statement that it would be impossible to get complete separation between petroleum fractions by bleeding a side stream from the tower is true. Practically as pointed out there are a great many instances when this is not desirable, and fairly close cuts can then be bled from the tower. This is usually true for the heavier cuts, seldom for the lighter ones.

Excellence in design and construction is no more important than close and easy control. Heretofore too great a burden has been placed upon the automatic controller. Automatic control should be given a minimum task, and should be independent of any other automatic control instrument and practically independent of the operation of the unit. Its purpose should be to decrease small irregularities, not to correct bad design.

Within the past two years single flash distillation processes have been used when another type of distillation might have been better. Topping gasoline and kerosene from a light Mid-Continent crude could be done more effectively if the crude were charged to the tower and the heater used to heat the base of the tower. Considerable study should be given to the selection of the type of distillation installed. Certainly there are a great many applications for the recirculation pipe still. In general it appears that a single flash distillation is advantageous when running to a small residuum bottoms without any cracking; fractional distillation when only light ends are to be removed; and the series still (two coils within a single setting) when topping and reduction with a small amount of cracking is desired.

A single tower from which a number of side streams are taken cannot be controlled by controlling top temperature of this tower. Side streams of a definite quality must be withdrawn from the tower at a definite temperature. The top temperature undoubtedly controls the temperature down to the point where the first cut is taken. From that point down every other temperature in the tower is dependent upon the rate of withdrawal of the first cut. The tower in reality is a number of towers set one upon the other and as such is subject to all temperature variations within the tower that occur with multiple towers, and should be designed with this in mind. Probably the ideal arrangement would be a weir setting arrangement controlled by an automatic temperature controller.

Objections to Mr. Bell's recirculating pipe still are: (*a*) A much higher steam consumption as mentioned; (*b*) a constantly changing set of operating conditions which must be controlled and which must result in more operating manhours per still; (*c*) higher maintenance on the furnace due to alternately heating and cooling, and (*d*) a possibility that continued recycling of the cylinder stock involving long-time and high temperature will result in considerably more cracking than in a once-through unit.

Referring to the Simms plant, the flow through the heater is only 2200 bbl. per day of an 18° Bé. fuel oil and this through two 3½ I. D. tubes in parallel. The outlet temperature is 840° F. and yet the still was so designed that no serious coking trouble is encountered. The overlap between the gasoline and gas oil is due to the absence

of steam from the bubble tower. The gasoline contained in the fuel oil is recovered at the cracking point.

R. B. Chillas, Jr.,* Philadelphia, Pa. (written discussion).—Referring to the heat required for fractionation, a heat balance on a single flash, single tower unit taking multiple side streams, similar to that indicated in Fig. 12 of the paper, will show that as the still outlet temperature is raised, the quantity of heat available for fractionation is considerably in excess of that needed to effect the fractionation of the lighter constituents of the charge. In other words, the heat available at the top of the column is sufficient to vaporize the naphtha from 6 to 11 times, consequently the reflux within the column is from 6 to 11 times the quantity of the naphtha overhead stream. It has been found, however, that with a reflux of 1.5 to 2 times the forward flow, the quality of the overhead fraction is so close to that obtained with the higher refluxes as to be practically indistinguishable one from the other. Therefore, it is usually unnecessary to introduce any additional heat merely to effect fractionation, since the heat which is put in to give the desired amount of vaporization will also give the fractionation required.

Concerning the discussion of the characteristics of the single tower unit, it seems to us that Mr. Bell has given an impression which differs somewhat from our own on the operation of this type of unit, particularly in regard to the quality of the side streams.

In a unit such as Fig. 12, the entire vapor from the still enters the column below the lowest fractionating plate. As these vapors rise through the column, the higher boiling components are successively removed from plate to plate, until, at the top of the column, only naphtha remains to carry all of the latent heat and that part of the sensible heat of the incoming vapor not taken out by the side streams. As a consequence of this, the reflux ratio increases toward the top of the column to the extent above mentioned.

On the lower plates in the column the temperature and vapor pressure relations are such that the liquid on a given plate retains only comparatively small amounts of the lower boiling components of the vapor passing through it.

Furthermore, when the liquid from any such plate is withdrawn from the column, its sensible heat content is high enough, and the latent heat of the accompanying light products is low enough to permit the removal of essentially all of these low-boiling constituents simply by passing an inert gas counter-current through the liquid in a small auxiliary stripping section. Steam is a convenient and efficient means. In the bottom of the column, the residue or bottoms is similarly stripped by a small amount of steam. In the upper part of the column, on the kerosene plate, for example, the physical properties (temperature, vapor pressure and liquid-vapor equilibrium composition) are such that the kerosene fraction drawn off from such a column usually does not need to be stripped, as just described.

H. S. Bell (reply to discussion).—We have also found that increasing the reflux ratio beyond 1.5 to 2 results in very little change in the character of the products. Under normal conditions it will rarely pay to exceed this figure. However, with these reflux ratios there is necessarily a small percentage of light products in the side streams. The heat withdrawn by the side streams is sufficient to effect further separation if it could be utilized, but in practice some other means of stripping this small fraction of light product must be resorted to if close separation is desired. Two ways are, of course, possible: first, lowering the vapor tension and in this case an inert gas would undoubtedly serve the purpose; second, the application of heat. The introduction of steam is a combination of both.

* Distillation Engineer, Atlantic Refining Co.

Relative to questions raised on the salt drums, I quote from a letter from Walter Miller of the Marland Refining Co.:

"The results vary so with different conditions that it is difficult to draw any general conclusions. We have operated at temperatures of from 200 to 350° F. Probably the best condition for settling we have found is 300° F., under which temperature the vapor pressure varies from 90 to 135 pounds.

"With fresh crude, good settling can be obtained with as low a temperature as 200° F., whereas on crude stored for over a year, practically no settling can be obtained.

"If there is 3 or more per cent. water in the crude and the salt is all dissolved, then satisfactory settling can be obtained, but if the water content is low and the salt is present as a solid no settling will take place.

"When running tank bottoms we have successfully drawn off 15 to 20 per cent. water with 250° F. and 30 lb. pressure on the drum. In the case of Amarillo crude containing 500 gm. per bbl. of salt, we have lowered the salt content to 100 gm., using a temperature of 300°.

"The drums hold 400 bbl. and therefore give us a settling time of about 1 hour."

Modernization of Shell Stills

By C. W. Stratford,* San Francisco, Cal.

(New York Meeting, February, 1928)

[During the last few years, the necessity for development work has been generally recognized by executives throughout the oil industry, resulting in greatly accelerated progress and the adoption of many noteworthy improvements in refining methods and equipment.

Several years ago, the Associated Oil Co. decided to improve distillation methods with the object of reducing refining costs. This extremely interesting work was entrusted to the writer, and W. S. James, now Chief of Research for Studebaker Corpn. of America, was selected as the principal collaborator. The latter contributed much during his two years with the Associated Oil Co., to the development work that has followed.

The writer extends to the Associated Oil Co. his appreciation for permission to disclose the details of distilling equipment.]

In petroleum refining the principal requisites of good economics are the separation of high-priced distillates from those of lower price; maximum yield of any desired distillate; lowest capital investment in refining equipment; lowest cost of operation and maintenance, and the best adaptability and flexibility of the same refinery equipment for handling crudes of widely varying characteristics. The first two items mentioned, separation and yields of distillates are determined by efficiency of fractionating equipment. Discussion in this paper is chiefly concerned with oil-heating equipment, combustion and fuel economy.

It has long been well known that velocity plays a very important part in all heat transfer systems. Any betterment in specific transfer rates in such systems must always involve velocity. Realizing this fact, we decided to adopt as a basic principle, the employment of energy to impart velocity required for high transfer rates through a heating diaphragm, and our method of modernizing obsolete shell stills is founded on this principle. Mechanical energy is usually cheap and its rational expenditure is returned in the form of greatly increased heat transfer rates, on both oil and gas sides of the sheet. Certainly there is nothing new in this principle, the only novelty being that of our peculiar method of application

On the oil side (Fig. 1) use is made of a centrifugal pump to jet the oil against the heated sheet thereby creating a high velocity sheet flow over the entire fired area. Such a pump is one of the most efficient machines, so far developed, for moving fluids. The oil, under pressure, impinging

* Technologist, Associated Oil Co.

on the transfer surface at high velocity, furnishes a continuous sheet of liquid in intimate contact with it, for the efficient absorption of heat as rapidly as it can be transferred. The continuous sweep of this liquid sheet over the transfer surface keeps it scrubbed clean and reduces the temperature of the oil film in actual contact with the metal, maintaining a minimum temperature difference between metal and oil.

On the gas side (Fig. 2) a forced draft fan, feeding air to the furnace, furnishes energy, first for intimately mixing the oil and air, and second for continuously spinning the combustion gases under the full length of the still. The function of spinning the combustion gases is to move the

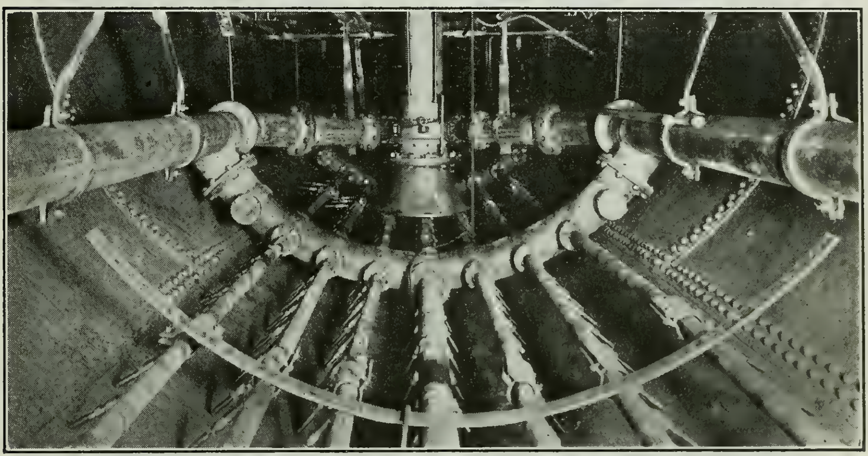


FIG. 1.—INTERIOR OIL-CIRCULATION MANIFOLDING AND STILL PUMP IN LATEST 12 by 45-FT. STILL EQUIPPED.

gas-film in contact with the still, and thus promote increased convection transfer over the entire bottom.

Our experience has shown that the heating capacity or transfer rate per sq. ft. in shell stills with oil circulation is equaled by very few oil-refining heaters of other types and probably exceeded by none. The fired bottoms of such shell stills, exposed to radiant heat at the highest temperature levels, in the combustion zone are immune from coking or other heating surface troubles. This is true also with direct flame impingement against the bottom.

Cost of Applying Oil Circulation

The application of oil circulation to shell stills makes possible the most efficient combustion with highest flame burst temperature and lowest excess air. The thermal efficiency of such heaters may be raised to any practical value, justified by the price of fuel and the allotted pay-out time. The cost of applying oil circulation to otherwise obsolete

bottom-fired shell stills is materially less than the cost of equivalent heating capacity in any other present type of heater. (We undertook the modernization of shell stills rather than instal pipe stills which were available and much more efficient than our old stills, because the cost,

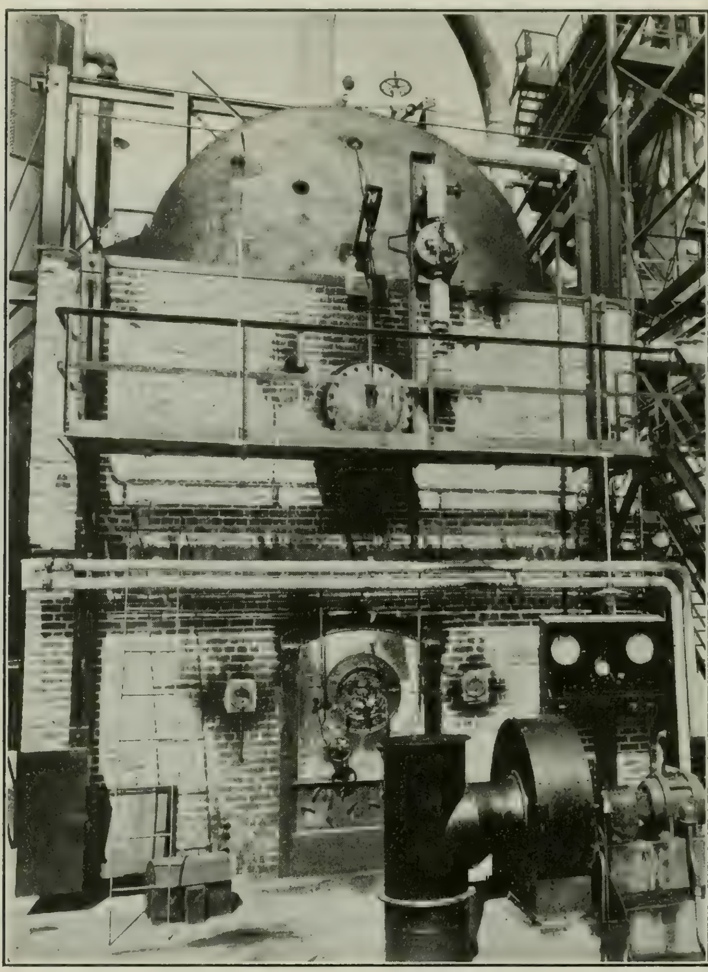


FIG. 2.—FIRING FRONT OF LATEST 12 BY 45-FT. OIL-CIRCULATION STILL SHOWING BLOWER, BURNER AND WINDBOX.

then, of pipe stills was high and the abandonment of the large number of shell stills already installed was considered inadvisable from the standpoint of capital investment.)

In the beginning, close contact with operating personnel developed much friendly opposition. This had a distinctively stimulating as well

as a sobering effect. Many operators asked how we could hope to better shell-stilling of petroleum when these heaters had been developed by the industry and used for a period of over 50 years without material change.

The First Installation

Most of the first period was passed in experimenting with combustion methods and desirable fire box construction and learning what had to be done to an ordinary centrifugal pump to convert it into a pump which would unfailingly and efficiently handle boiling oil. The first four stills equipped were 10 ft. dia. and 40 ft. long. Against the bottom of each, 750 gal. per min. of oil was pumped. A charging capacity of 5300 bbl. was attained, vaporizing about 42 per cent. This was a throughput of more than five times the former capacity of the still without agitating steam. Each of these stills, so equipped, was operated as a single continuous distilling unit charging crude in and taking main vapor and residuum out. The side walls of the furnace under these stills were air-cooled, delivering air to the wind box at approximately 300° F.

Following the first installation, six stills 12 by 45 ft. were equipped with oil-circulating pumps, discharging 1100 gal. per min. against the bottom. (Fig. 3.) No radiant or convection coils were applied. These stills were operated as individual units. They were run at a capacity of 6500 bbl. per day each, 40 to 50 per cent. being vaporized. A trial of potential capacity of a few hours' duration was made during which time a throughput of 9400 bbl. per day was reached with a single still. The application of good fractionation to this battery has resulted in a material increase in recovery of gasoline and in improved over-all realizations on distillates.

The last 12 by 45-ft. still was equipped with a circulating pump having a capacity of 3600 gal. per min. at 35 lb. pressure. A rate of 9200 bbl. per day was reached with this still but the rate was decreased to 8500 bbl. per day in order not to overrun the capacity of fractionating equipment.

A small tubular convection bank was applied to this still. The average gas temperature entering the convection bank is 1200° F. and temperature of gases out to stack, between 585° and 700° F. The variation in the temperature of the outlet flue gases is determined by the temperature level of the oil pumped through the convection bank. Radiant tubes were applied along the front face of the bridge wall to prevent anticipated overheating of the bridge wall and to absorb heat from the end of the flame burst. The radiant coil is simply an addition to the radiant absorbing surface of the still bottom. Operation has shown the tubular radiant surface to be unnecessary, though possibly useful, as a separate heater with certain flow hook-ups of the distilling unit.

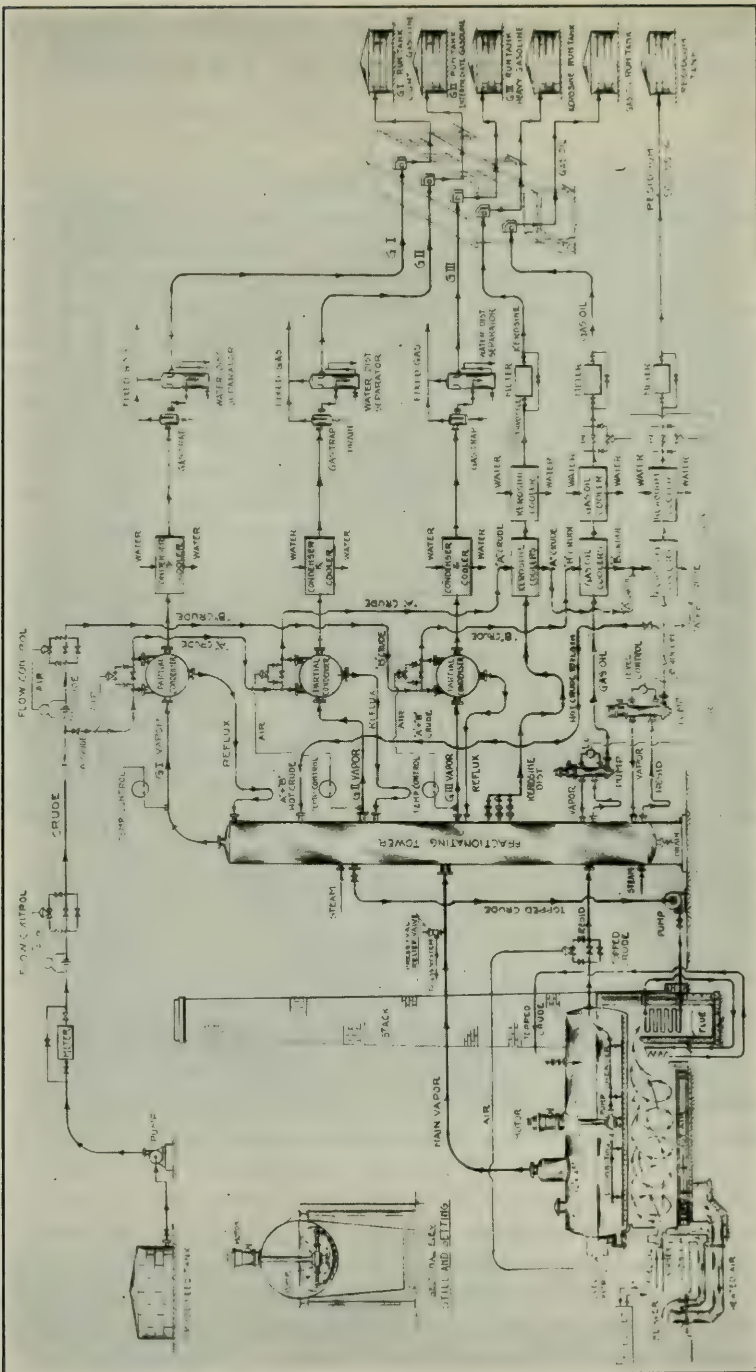


FIG. 3.—FLOW-CHART; OIL CIRCULATION APPLIED TO A 12 BY 45-FT. STILL.

Charging Capacity

In equipping all of the 11 stills with oil circulation we naturally encountered many unforseen difficulties. While our anticipation of probable capacity of heaters seemed too high to many during the design stage, in every case we greatly underestimated capacity actually attained. Owing to the present inadequacy of old flues and stacks to handle the greatly increased volume of flue gases, and the limitations imposed by some vapor handling and exchange equipment, it has been impossible, so far to determine the top capacity of any of these heaters. However, with flue gas economizers installed, it is the writer's conservative opinion that the probable charging capacity of an outside-fired, 12 by 45-ft. still, running refining crude, and vaporizing approximately 50 per cent., lies somewhere between 10,000 and 12,000 bbl. per day.

Results

The first result of operating oil-circulation stills attached to fractionating equipment and running on refining crude was the shutdown of a number of shell-still batteries and pipe-still toppers. Direct fractionation of distillates eliminated the need of re-run stills. The expanded distilling area thus suffered a very profound contraction for the same normal throughput. It was also necessary to contract operating personnel correspondingly. Many boilers formerly fired for generating steam for distillation were taken off the line since the use of agitating steam in the stills was eliminated. The present use of steam is restricted to bringing heaters up to running rate and to stripping sections of the fractionators. The over-all fuel consumption has been reduced to less than one-half of old requirements, now varying on the average between 0.9 and 1.3 per cent. by volume. In the last two years, the total cost of distilling refining crude has been reduced by more than half. Regarding the service factor, it is interesting to note, that the last oil-circulation still, in continuous operation, has required no cleaning since it was first fired in June, 1927.

In general, shell stills have an advantage in that a large surface of oil is exposed in them to free evaporation. Though many refiners may object to fire hazards involved in shell-still operation, with oil circulation against the bottom, this hazard is reduced to a negligible minimum.

California crude petroleum is not the easiest type of oil to distil. It is wet, when charged to the stills, which causes a perceptible increase in fuel rate. California crude is considered dry when it contains only 1 per cent. of water and the water content usually varies between 2 and 3 per cent. This water, in the crude, contains much salt which rapidly fouls the tubes of heat exchangers. Salt crystals in the residuum within the still tend to fuse to the fired sheet at high firing rates and thereby to

create hot spots. That was the compelling reason for increasing the quantity of oil jetted against the bottom in the last still constructed.

In practically all development work, it is often discouraging to sense the rapidity with which our most cherished conception of something seemingly new passes into near-obsolescence. This frequently occurs during the period between completion of design and readiness for operation. Such a situation is always certain to obtain in any industry which has been unusually slow to apply some of the timeworn facts long since recognized and applied by other industries.

More Economical Modification of Shell Still Desirable

With the background of facts established by commercial operations, above disclosed, and profiting by experience had during the development period, the writer wishes to propose another reasonable forward step and apply what appears, now, to be an even more economical method of modifying shell stills. On referring to an analysis of past installation costs of outside-fired, oil-circulation stills, it is seen that expenditures made for raising the stills and rebuilding masonry into satisfactory fire boxes with air-cooled side walls and floor, represent, as in similar furnace construction, a high percentage of the total cost of modification. This analysis naturally suggests the desirability of finding ways and means of reducing or preferably of entirely eliminating the cost of rebuilding old shell-still settings. Where present fire boxes are satisfactory for increased firing rates additional masonry cost is eliminated.

Turning to other lines of endeavor for inspiration, we find the Scotch boiler equipped with a firing tube and the burner set directly in the end of it. No trouble is experienced with the maintenance of the fire tube and high transfer rates are obtained to non-mechanically moved water.

All over Europe there are hundreds of shell stills equipped with one or two firing tubes. The standard Brunn Koenigfelder type of shell still used in Europe is approximately 30 ft. long, 10 ft. dia. and fitted with two firing tubes 32 in. in dia. The surface of two such tubes is greater than that available on the same still when placed above a fire box and fired on the outside in the normal way. Combustion for Brunn Koenigfelder type stills is accomplished in a Dutch oven attached to the front of the still and the incandescent gases pass from this combustion chamber to and through the firing tubes. No difficulty is had in the maintenance of the heating tubes. Attempts at direct firing into the tubes of Brunn Koenigfelder stills have been unsuccessful because of coking and burning of the oil on heating surfaces. It is logical to conclude that oil circulation can be applied to the heating tubes of this type of still, even more advantageously than is the case with oil circulation outside fired shell stills in which all sediment in the oil tends to settle to the bottom, requiring

unusually vigorous circulation of oil to prevent deposition and coking of the bottom.

Application of Inside-fired Tube

The following proposed plan of modification appears to meet all requirements of reduction in cost and promises even greater efficiency. Assuming that a still 10 ft. in dia. and 30 ft. long were to be converted, the application of a single-fire tube of about 3½ ft. in dia. would give ample heating surface and furnace volume to satisfy all necessities of combustion and heat absorption, by the oil. This tube may be offset from the center of the still to allow for the installation of a submerged, vertical still pump. The oil-distributing manifolding can then be wrapped around the firing tube and the nozzles directed so as to impinge jets of oil against it. Tests show that the sheet flow of oil circulation covers this type of surface just as perfectly as it does that of the bottom of an outside-fired still. A mechanical atomizing burner can then be directly applied to the end of the fire tube.

In order to promote convection transfer from incandescent gases to the heating surface, it is also proposed to spin the gases of combustion at high r. p. m. giving a velocity over the heating surface of over 100 ft. per sec., for the entire length of the heating tube. This is now being successfully done in some fire tube boilers. The removal of spinning gases from the stack end of the heating tube demands a special solution. This is accomplished by unwinding them through a volute. Spinning energy can thus be economically converted into pressure to drive the issuing gases through a circulatory heating system, such as an air preheater or convection bank or through both. Such a combination assures high over-all thermal efficiency of the unit.

It is obvious that this plan would be good from many points of view. All expensive masonry is eliminated. There can be no loss of combustion gases at high temperatures from such a tubular combustion chamber, neither can there be any infiltration of cold air to decrease efficiency. In view of high transfer rates recently obtained in fire tube boilers, the application of a similar fire tube surface in a shell still would very probably result in greatly increased transfer rates per square foot of heating surface compared to that already obtained in an outside fired oil-circulation still. This compressed type of high capacity heating unit is adaptable to many diversified uses, being applicable to steam boilers and to heaters of other liquids as well as oil.

Tendency toward High-percentage Vaporization

Progress in petroleum refining has recently developed a decided movement toward vaporizing greatly increased percentages of crude charged to distilling units. The economic necessity for better realizations

on refining operations has had a controlling influence on this tendency. High percentage vaporization often necessitates dividing the heating operation into two stages. In the first stage, gas oil and more volatile distillates are separated. In the second stage of distillation at high temperatures, for the recovery of wax distillate and more viscous lubricating stocks, no particular difficulties are encountered until temperatures in the neighborhood of 600° F. are reached. In distilling most crudes undesirable cracking occurs at temperatures of between 600° and 750° F., especially when the period of heating is long. Such cracking always greatly reduces yield of lubricating distillates and it may seriously interfere with recovery of wax from distillates of paraffin base. To eliminate or reduce cracking several methods have been employed. A large quantity of steam introduced in the evaporating chamber of a distilling unit lowers temperatures required for vaporizing a given percentage of distillate but large quantities of steam are expensive. Distillation under high vacuum with steam injection lowers further the necessary temperature of oil in the heater. Distillation of heavy crude under high vacuum without steam has not proved to be altogether satisfactory. Refining by all of the methods noted has been accompanied by an undesirable degree of cracking when the heating is done in practically any type of oil heatee of conventional design where relatively low flow velocities are mainr tained and the heating time is long. This indicates a need of improving the means of heating hydrocarbon liquids when decomposition is to be avoided.

Influence of High Temperatures and Time on Cracking

Data on the cracking art show clearly that chemical decomposition of hydrocarbons, by heat, is greatly influenced by the period of time during which oils are held at high temperatures. In most heaters, now available, the liquid volume capacity divided by charging flow rate through heater gives a time factor that is many times too large to avoid a "soaking" effect and cracking where it is not desired. Unquestionably, there is an urgent need of equipment in which oil may be heated to desired final temperatures within an extremely short period of time. The ideal system would be one in which the temperature of distillation is reached in a few seconds; vaporization accomplished in a zone of lowest possible hydrocarbon pressures to keep down final temperatures; finally the distillates rapidly cooled after fractionation or separation.

How can such specifications be met? In the first place, very rapid heating of oil can be done only with an absorbing surface to which practically all heat is transmitted by radiation at high temperatures. The oil in turn must absorb this transmitted heat as fast as delivered with lowest oil film temperature. The time factor must be small and the total liquid

volume of the heater must also be small, which is simply another way of stating that the specific heat transfer rate must be unusually high.

Heater Designs

Of all direct heater designs, that might be satisfactory for this purpose, there are two that stand out, in the opinion of the writer, as heaters which seemingly have a good chance of ultimate success. The first conception is a heater constructed with tubes of small diameter, spirally wound, and the second conception is an inside-fired heater with oil circulation in the annular space between the firing tube and the collector tube. In the construction of the first with small tubes, it would be preferable to wind the spiral elements around a refractory core and fire it at the top in the annular space between the coil of tubes and the inside of the circular furnace enclosing it. This arrangement would permit the utilization of centrifugal force, developed by high velocity flow of oil in the spiral tubes, to throw a liquid oil covering over the surface exposed to highest absorption rates in the furnace. Any vapor formed could ride on the inner part-diameter of the tube which would not be exposed to radiant heat. The chief disadvantages of such a small tube heater are high pressures required to drive the oil through the coils, difficulty or impossibility of cleaning and the low heating capacity of the back half of the tubes that are not exposed to fire. It would be imperative to operate at a fixed, full rate with optimum velocity of oil flow to avoid coking.

Oil circulation applied to this special heating problem apparently would meet requirements of operation and presents no particular difficulties of construction or maintenance. An oil-circulation type of heater would comprise a firing tube against the outer surface of which the oil to be heated is impinged. Surrounding the firing tube is placed a concentric collector tube enclosing a thin annular space of small total volume for the flow of oil. Manifolding for the uniform distribution of oil, from the discharge of the circulating pump to the nozzles, is attached to the outer shell as is also the manifolding for receiving the heated oil as it is forced from the annular space through slots and passes directly to the vaporizer. The circulating pump, being incorporated in the vaporizer, receives the separated oil discharging a portion from the system and sending the remainder back through the heater with the fresh feed. Energy put into the circulating pump is usefully expended in imparting desired high velocity to the sheet flow of oil over the heating surface. All of this surface "sees" the fire and transfers heat at a uniform rate. Interconnection of power for the fuel set and circulating pump would make burning of the sheet improbable. The firing tube could be easily withdrawn for inspection. It is evident that charging rate to this heater would not influence velocity of oil over the heating surface though the time factor would be changed.

Before a rational design of any type of heater can be undertaken it is imperative first to study the source of heat to be used and the mechanism of combustion. The subject of combustion is entirely too extensive to permit much discussion in this paper. However, the writer believes that it is worth while to touch on a few of the frequently neglected high spots.

The petroleum industry as a whole uses a tremendous quantity of fuel. The largest single item of expense in distilling oil is that for fuel, yet its proper utilization has received relatively little attention.

In all considerations of the economical use of fuel too much emphasis cannot be given to the importance of carefully analyzing all the factors that influence combustion. Combustion in any oil heater should be just as complete as that which occurs in the cylinder of an internal combustion engine, fed with a correctly proportioned mixture of air and fuel.

Oil Burner Equipment

An oil burner should provide means for easy adjustment of air-fuel ratio, should comprise a circulatory fuel oil feed for control of fineness of fuel atomization, and it should be capable of intimately mixing the air and atomized fuel. In addition, it should also be equipped with a tangential air-inlet diffuser giving control of the r. p. m. of the components of combustion passing through the firing Venturi. Such a burner will feed an explosive mixture into the combustion chamber. There is no danger whatsoever in its employment, providing a torch for lighting is always introduced before injecting the mixture. The requirements for burners using combined oil and gas, gas alone, or powdered coal are identical. Only such carbureting burners will permit the realization of maximum fuel economy.

The flame burst, using gas as fuel, is much less luminous than that from oil or powdered coal. It is therefore more difficult to absorb radiant heat from incandescent gases of combustion when using gas as fuel, than it is from the incandescent carbon particles of a flame burst when using oil or powdered coal. The chemical constitution of the gases of combustion also effects radiant absorption. If high radiant absorption is to be obtained with gas fuel, it is advisable to burn at least a small quantity of fuel oil with it. All flame burst temperatures are greatly elevated by increase in temperature of the air fed to combustion. For this reason, it is always desirable to heat the air to as high a temperature as is practical in order to elevate flame burst temperatures to a maximum. As high values of CO_2 are approached in combustion any lack of homogeneity of the air-fuel mixture becomes more apparent and should be corrected. In a well conceived combustion system, it is not difficult to maintain a CO_2 value of between 13 and 14 per cent.

The absorbing surface, on the fired side, is an item of great importance in all heating systems. Though the temperature of this surface influences

radiant heat transfer but little, its temperature does greatly influence transfer by convection. As a consequence, it is of advantage to lower absorbing sheet temperatures as much as possible if high convection transfer is to be had. Also, for the reason that velocity has a decided influence on convection transfer, the gases of combustion should be made to travel at high velocity over the absorbing surface. The requisite velocity can easily be imparted by spinning the components of combustion. Another distinct advantage of rotating the gases of combustion in circular chambers over periferal absorbing surface consists of utilizing centrifugal force to flow the hottest gases of lowest specific weight to the axis of rotation, thus maintaining a core of highest temperature to support combustion. Spinning combustion within firing tubes gives rise to practically no heat insulation by deposition of finely divided solids. In the light of present knowledge, it is quite safe to assert that we are still far from having reached any insurmountable limitation in rates of heat absorption from combustion gases by clean metal sheets, or the transmission of heat through them.

Heat Transmission Difficulties

Most of the serious difficulty of heat transmission seems to be on the side where the liquid fails to absorb the heat transmitted. Examining the principal causes of failure of heat absorption by liquids we find nothing that cannot be corrected. The entire transfer surface should be swept by a continuous sheet of liquid moving at high velocity in most complete and intimate contact with it. This flood of liquid must be of sufficient quantity to furnish an adequate medium for absorbing all the heat transmitted. Immediately after contact with the heating sheet the liquid should be allowed to evaporate freely. Flow at high velocity assures perfect cleanliness on the liquid side of the sheet, guarantees lowest film temperature, and prevents the accumulation of silt, carbon or salt films having high heat-insulating properties. The heat-absorbing capacity of vapors or of these vapors mixed with atomized liquid is many times lower than that of the liquid. From this fact it follows that a heating surface can only be sufficiently protected from failure by the sweep of liquid, when this surface, on the fire side, is directly exposed to absorption of radiant heat at high temperature levels and at high specific rates. The system of forced circulation fulfils all requirements of highest transfer rate. It makes every ton of metal in the heater do more work than it has done before. The degree of protection from failure provided for any heating surface is most definitely measurable in terms of the amount of energy efficiently expended in moving the liquid over that surface to conduct the heat away.

DISCUSSION

Mr. Stratford, in reply to questions, stated that the heat transfer rate was 30,000 to 40,000 B. t. u. per sq. ft. per hr., depending on furnace temperatures, nature of charge and extent of distillation. Also, that the temperature of the gases over the arch was 1140° F. The temperature of the still bottom measured with pyrometers welded to the bottom was 92° above the average oil temperature in the still. Circulation of oil at the rate of 3600 gal. per min. required 80 horsepower.

Chapter X. Heat Utilization*

Screened Radiant Heat and Its Application to the Petroleum Refining Industry

By A. E. Nash,† Philadelphia, Pa.

(New York Meeting, February, 1928)

This title is somewhat of a misnomer, because it does not accurately describe the phase of heat generation and application coming within the scope of this discussion. This paper is concerned primarily with that particular phase of radiant-heat transfer sometimes erroneously referred to as "shielded" radiant heat, to differentiate it from the open radiant heat of either flame or settings, in which the actual source of the radiant heat is a small incandescent furnace composed of a highly conductive superrefractory, within whose walls the combustion of the fuel is completed. This small furnace is usually located directly in the furnace proper, and although its refractory walls do shield the heat-absorbing surfaces from contact with the gases of combustion, there is no interference with the radiant heat given off by the furnace itself. We do not believe it either necessary or advisable to shield or screen radiant heat when properly controlled and applied. We do believe it essential to prevent the excessively hot gases of combustion from coming in contact with those parts of the heat-absorbing structure that are already receiving heat at high rates by radiation. In connection with any process for the refining of oil with which we are familiar, we are convinced that it is most advantageous to transfer the maximum of the heat generated in the form of radiant heat, applied directly to the heat-absorbing surfaces without the interposition of any form of shield or screen to prevent or reduce the radiant-heat transfer.

While the term radiant heat is broadly used to cover all heat energy transferred from one body to another by radiation, in contradistinction to heat given up by gases in direct contact with the heat-absorbing structure (convection) or transmitted simply by conduction, in furnace work it is perhaps more often limited to the heat rays given off either by

* A paper, "The Role of the Combustion Engineer in Refining," by Joseph W. Hays, Mid-Continent Petroleum Corpn., Tulsa, Okla., was presented by title at the New York Meeting, 1928, and appears in Mining and Metallurgy (March, 1928) 126.

† Alcorn Combustion Co.

the gases or the refractories used in the furnace construction, which are themselves at sufficiently high temperatures to show "color." Such energy rays approach the ultra-red rays, and in general act according to the laws which govern such light rays.

Former Objections to Radiant Heat

It is generally conceded that radiant-heat rays travel in straight lines, and that the intensity of the rays from any one point varies inversely as the square of the distance. It should be remembered, however, that in a furnace setting the radiant heat is confined within the walls of the furnace, and is reflected and re-radiated from point to point, until ultimately taken up by the heat-absorbing structure, lost either by conduction through the ground and setting, or carried away by the combustion gases. This condition, therefore, tends to equalize the actual rate of transfer, and the relative distance between the primary source of heat and the heat-absorbing surface is of minor importance.

The rate of transfer then depends primarily on the temperature differential, and as expressed by the Stefan-Boltzman law,

$$H = 1600\left[\left(\frac{T^1}{1000}\right)^4 - \left(\frac{T^2}{1000}\right)^4\right]$$

where H = the heat in B. t. u.'s per hour, and T^1 and T^2 the respective absolute temperatures in degrees Fahrenheit. It should be noted that the rate of transfer, which varies with the fourth power, is very greatly affected by the relative temperatures, and extremely high transfer rates can be secured. Properly controlled, this is a most desirable condition, but where the furnace is not correctly designed, especially when the radiant heat is applied in addition to convection heat from the gases, difficulties may arise.

It is because of such conditions that only a few years ago radiant heat was regarded as something to be avoided wherever possible. Furnace builders designed their units to this end, and openly stated that "surfaces for heating oil must not be exposed to heat directly radiated from the furnace." At this time a limit of 1500° F. was commonly set and refinery engineers generally required that the temperature to which the oil was subjected should not exceed this figure. In arriving at this limit, pyrometer readings were taken at predetermined points, which, due to radiation loss, may or may not have been indicative of the actual temperatures in use. Even more recently, men of the highest standing and of recognized authority have been opposed to radiant heat and have gone to extreme limits, even at the expense of low efficiencies and high costs, to avoid it. That there was reason for this attitude so general in the petroleum-refining industry is unquestioned, but it was due to the fact that in ordinary furnace construction, high gas temperatures result

in incandescent settings, and the radiant heat from the extremely hot surfaces (frequently 2200° to 2400° F.) when applied in addition to the convection heat from such high temperature gases, gives a total heat input *in limited areas* which is more than either the metal or the oil will stand. For example, with a temperature of 2400° F., assuming an oil temperature of 800° F., the combined rate of heat transfer by radiation and convection would approximate 110,000 B. t. u. per sq. ft. of exposed surface. This would probably cause trouble and such conditions should be avoided.

Precautions to Prevent Radiant Heat

To this end, various ideas in construction and operation were tried with indifferent success. Dutch ovens were added to the furnaces with the idea of completing combustion in a zone which did not directly "see" the tubes or shell structure. Bridge walls and arches were designed to prevent the direct action of radiant heat, while some refineries used entirely separate firing chambers, the heat-absorbing structure being located in a section supposedly separated from any direct radiant heat. These attempts, however, proved unsatisfactory, for when there was no means of absorbing the heat generated in the firing chambers, the temperature built up to a point where the refractories failed, and the temperatures carried over into the other section of the furnace, resulting in burned-out tubes or shells. To avoid this condition and to keep the temperature within the required limits, excess air was purposely supplied and this air used to reduce the gas and wall temperatures. This naturally resulted in very low fuel efficiencies and high operating costs.

As long as the management of the refineries was satisfied with their daily capacity or throughput, and economy in fuel was not an essential factor in plant operation, it mattered little whether the heat necessary for any process was applied by convection, radiation or conduction; or a combination of any of these methods. When, however, the demand for finished products made it necessary and profitable to greatly increase throughputs, the tube still largely displaced the shell still, both for straight distillation and for cracking processes. Economy in operation also became a factor at the same time and every effort possible was made to reduce the amount of fuel consumed per barrel charged. The most obvious method of reducing fuel consumption was to reduce the amount of excess air. While this resulted in saving fuel, the increase in tube trouble and resulting loss in time on stream, more than offset the savings in fuel. This was particularly true in the operation of such tube stills and cracking coils as required high temperatures and which had a greater tendency to "coke up" the tubes. The heavier the charging stock, the more pronounced the difficulties. Observation indicated that as the refractories increased in radiance, the direct result

of increased combustion temperatures, tube failure became more pronounced and therefore radiant heat was blamed.

To prevent the walls from becoming radiant, some furnace builders provided tubes, frequently covered with refractories, for the specific purpose of keeping the walls at a low temperature. However, with good combustion conditions the resulting temperatures still caused trouble and it was necessary to use large quantities of excess air. Such construction was frequently referred to as "shielded" radiant heat, although essentially this construction was a blocking or an attempt to eliminate the radiant heat. Actually the tubes so covered received little or no heat directly as radiant heat, since the refractories were essentially impervious to the radiant rays. These tubes, therefore, were primarily dependent on the heat conducted through the tile covering, and since these tile were in most cases composed of fireclay, which is not a good conductor of heat, the transfer rate was low. To overcome this condition, some of the tile were removed at intervals until the desired rate of transfer was secured or until tube trouble resulted.

Certain engineers utilized the idea of tempering the gases by recirculating a portion of the waste gases, and forcing these gases back again into the furnace. This helped conditions and permitted better economies, at the same time increasing the heat transfer rate because of increased gas velocities. It necessitated, however, expensive blowers and ducts, greatly increased the first cost, and at the same time was a source of constant expense for both power and maintenance.

Conditions for Furnace Efficiency

The importance of furnace efficiency has now become generally recognized and the following conditions are regarded as almost fundamental:

1. Sufficient air for complete combustion of the fuel but with little or no excess. A preheated combustion air further improves operating conditions and reduces stack losses.
2. Thorough mixing of the fuel and air.
3. High furnace temperatures until the fuel is completely burned.
4. Sufficient furnace volume to insure the necessary time for the combustion to be completed before the gases come in contact with the heat-absorbing structure, since otherwise secondary combustion may result accompanied by excessive temperatures or incomplete combustion.
5. Proper arrangement of the heat-absorbing surface to insure uniform and efficient heat transfer.

In this connection the effect of high temperatures on the time required, and consequently on the necessary furnace volume, should be kept in mind, since the speed of the combustion reaction is very greatly increased by increasing the temperature at which combustion takes place.

Any heater constructed to avoid the transfer of direct radiant heat must of necessity depend primarily on taking the heat from the gases by convection. This is best accomplished by making the gases wash the tubes at rather high velocities, therefore the tubes are usually grouped in high, narrow banks, the restricted cross-section causing the gases to travel at the desired rate. The first and second rows of tubes in such a bank are subjected to the highest temperature gases, and at the same time receive practically 90 per cent. of any radiant heat that may be reflected from the walls. This condition compels these first few tubes to take up a very large proportion of the total heat input, and these are the tubes which in general give the most trouble. The remaining rows usually absorb heat at comparatively low rates.

Obviously, any attempt to increase the throughput of a unit by increasing the temperature of the gases would result in still greater overloading of the tubes in the first few rows. If, however, the radiant-heat temperatures can be properly controlled, advantage can then be taken of the correspondingly higher transfer rates, and the necessity for high gas velocities is avoided. Under these conditions, a very much greater number of tubes can be exposed to the heat radiated and a wide bank of only a few rows of tubes can be used. That this principle is correct is indicated by the present trend in boiler design where, particularly in central-station work, the necessity for operating at maximum ratings has resulted in furnace designs and operation in which every effort is made to bring the percentage of radiant heat to the maximum. Highly preheated combustion air, carefully regulated, is used to secure high furnace temperatures and the gases are made to wash the furnace walls so that a maximum of their heat is transmitted to the tubes as radiant heat. This condition has been carried to a point where the refractories themselves are the limitation.

Probably the best example of a radiant-heat furnace would be one heated by electrical resistors, where there are no combustion gases to handle. This type of furnace is in common use in the laboratories and among the oil chemists where a close regulation of temperature and a uniform distribution and application of the heat is essential. This then would be the ultimate in furnace design and the ability to approximate these conditions should be the aim of the engineer. At the same time the coil design should be so handled that each and every tube absorbs heat evenly and at as high a rate as circumstances permit. Not only do ineffective tubes greatly increase the first cost, but because of the added resistance, particularly where high oil pressures and velocities are in use, they very considerably increase the cost of pumping, both for power and for equipment. Because of this feature it is frequently poor economy to rely on additional tubes to reduce the exit-gas temperature, which can be done at less cost and more effectively by air heat exchangers, provided the increased gas temperatures do not cause difficulties.

Radiant-heat Furnace

Comparatively recently improvements in refractories have made possible furnace designs which permit of the combustion of the fuel at extremely high temperatures, and with little or no excess air. These refractories are extremely dense, have a high factor of conductivity (roughly 8 to 10 times that of ordinary fireclay), are not impaired by the gases of combustion, and will withstand the highest temperatures that can be secured in commercial operation. A refractory composed of practically pure silicon carbide grain, known as carborundum, answers these requirements.

By taking advantage of these valuable physical characteristics to produce and control radiant heat, a furnace can be designed (Fig. 1) which will have many of the desirable features of an electrically heated furnace without the excessive costs of installation and operation. To this end, both the fuel and the necessary air for combustion are introduced and burned within a tunnel or long chamber having carborundum walls and known as a carboradiant or carborundum furnace. In such a furnace all of the essentials for higher combustion efficiency previously noted are secured. The necessary air for combustion can be closely controlled and may be preheated to almost any desired temperature. The fuel (either gas, well atomized oil, or powdered coal) with the air for combustion, passes through the restricted cross-section formed by the carborundum walls at velocities of several thousand feet per minute, insuring complete mixing of the fuel and air. Since the combustion takes place completely within the carborundum walls, and preferably with an already preheated combustion air, extremely high temperatures are generated; which, however, are entirely screened from the heat-absorbing structure by the carborundum walls. The gases, therefore, cannot become chilled and the combustion is carried out without any retarding action whatever. These ideal conditions result in much higher combustion rates, and experimental work indicates that a heat release many times in excess of common practice can be secured without difficulty.

The high internal furnace temperature results in the carborundum walls becoming incandescent, and in operation they assume a balance depending on the amount of heat being generated, and the heat being absorbed. Because of the high conductivity of the carborundum tile, the heat easily passes through the furnace walls, and in practice the outside surface usually assumes a temperature of from 1400° to 1600° F., thus providing a positive source of radiant heat. This temperature can be more or less controlled by varying the furnace proportions, and can be materially increased by using highly preheated combustion air and relatively smaller areas of heat-absorbing structure. This provides a means of generating heat under almost theoretical combustion conditions which can be so controlled that almost any desired temperature can be

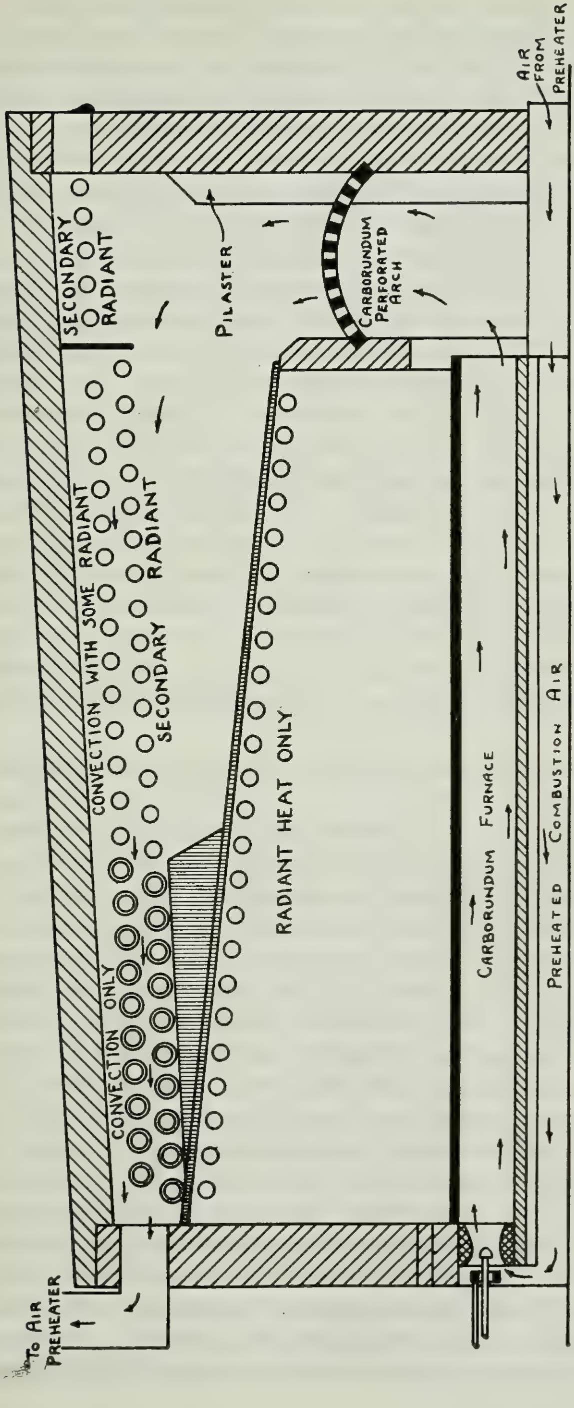


FIG. 1.—RADIANT-HEAT FURNACE.

maintained. Since a maximum of the heat generated is disposed of as radiant heat, the heat left in the gases is materially reduced, resulting in lower gas temperatures, and the necessity for recirculation is eliminated. Moreover, with little or no excess air the gas volumes are smaller, and in consequence the stack losses are reduced to a minimum.

By the use of carborundum furnaces, therefore, the general furnace design can be greatly simplified and the cost materially reduced. The heat-absorbing surface may be divided into two sections, one of which is heated only by radiant heat so evenly distributed and so closely controlled that oils, even at high temperatures and pressures, can be subjected to high heat input without danger to either the structure or to the oil. The remaining tubes take their heat from the resulting waste gases which, having given up a considerable portion of their heat, are necessarily at lower temperatures. As combustion is entirely completed in the carborundum furnace, there is no danger from secondary combustion. A higher average rate of heat input can therefore be maintained, and a lesser amount of heating surface or tubes is required. The fact that a considerable portion of the setting is completely separated from contact with the combustion gases permits of the use of special insulating refractories, having relatively poor resistance to flame erosion but high insulating value. This construction insures a minimum of radiation losses with lower construction costs. The size of the units for the same capacities can be made less and the cost of construction further reduced.

Control of Heat Distribution with Radiant Heat

The ability to control the heat distribution where radiant heat only is used is most advantageous in cracking, and offers a simple means of providing a closely controlled soaking period. For example, it has been pretty well established that if three rows of tubes are used in the section heated only by radiant heat, the respective rows will take up heat in the proportion of 6–3–1. That is, if the row nearest the source of heat absorbs heat at the rate of 12,000 B. t. u. per sq. ft., the second or middle row will take up heat at the rate of about 6000 B. t. u., while the heat input in the upper or third row would only be about 2000 B. t. u. per sq. ft. This ratio is naturally somewhat dependent on the oil temperatures. It is obvious, therefore, that if a greater rate of heat input is desired, one or at the most two rows of tubes should be used. For pipe heaters this works out to best advantage. However, in cracking, some refinery engineers advocate a soaking period or time after the oil has attained a cracking temperature, during which heat is supplied at a very moderate rate, sufficient to raise the temperature very slightly and at the same time supply such heat as may be required for cracking. This condition can be readily secured by a third row of tubes heated only by radiant heat.

Recent developments in cracking in the vapor stage, where higher temperatures are required, and where the oil vapor does not take away the heat as rapidly from the tube walls, have made even heat distribution and application essential. Here the advantages of controlled radiant heat are obvious.

Advantages of Radiant Heat

To sum up, therefore, it is believed that, contrary to previously accepted ideas, radiant heat, when properly controlled, is a most desirable means of applying heat to petroleum products, since by its use the following advantages may be secured:

1. Higher rates of heat input into the oil without danger to either the structure or to the product.
2. More uniform heat input over the entire heat-absorbing surface, since the variable of excessively high temperature gases is eliminated.
3. Correspondingly smaller and less expensive units for the same throughput.
4. Better fuel economies, since there is no necessity for large quantities of excess air, and better combustion conditions result, with heat losses reduced to a minimum.
5. Higher yields under comparative conditions, with improved products, since uniform heating keeps the formation of coke and fixed gas at a minimum.
6. In the case of cracking coils and pipe heaters, a greater percentage of operating hours, as the lack of coke formation and absence of tube trouble reduces the necessity for shutdowns.
7. Safety. An even heat "bath" for that part of the equipment carrying oil at high temperatures and pressures, with no possibility of excessive temperatures from secondary combustion.

It is apparent that the trend of the industry today demands close attention to the above conditions. Cracking in the vapor stage will probably require even higher temperatures than are now in common use. Moreover, the vapor under these conditions possibly will not take the heat away from the metal surfaces with the same rapidity as the oil does in the processes now used. This will undoubtedly result in refiners demanding higher rates of heat input but without too great temperature differences. Uniform heating will be essential, and it is believed this can best be secured by controlled radiant heat.

At this time units are in operation in which a heat input of better than 30,000 B. t. u. per sq. ft. of tube area is secured at certain parts of the coil. Other parts of the same heater are absorbing heat at greatly reduced rates. If it can be demonstrated that tube structure and the oil being processed can withstand such rates of transfer commercially, then with

the even heat distribution possible through the use of radiant heat only, a much higher average rate of heat input can readily be maintained. To secure this condition it is essential that the tubes shall receive the radiant heat rays directly, without the interposition of any shield or screen whatever, but rather with as many tubes as possible so placed as to receive the maximum of the radiant heat available.

A heating coil designed to insure such conditions, and operating at the higher temperatures now coming into use, might take the form shown in Fig. 1, although the principles involved permit of several modifications of the general arrangements. To illustrate what might be expected in the operation of such a unit, and to indicate the relative transfer rates which might be expected, we give the following estimated figures based on 28-ft. lengths of exposed tube of 4 in. O. D.

Assuming a generation of 30,000,000 B. t. u. and an over-all efficiency of 80 per cent., which we are confident can be secured by passing the waste gases through an air heat exchanger and supplying a preheated combustion air, the heat input to the oil should approximate 24,000,000 B. t. u. This would be divided among the various sections of the tube bank roughly as follows:

24 radiant tubes, 672 sq. ft. @ 20,000 B. t. u. per sq. ft. average	13,440,000	radiant only
20 secondary rad. tubes, 560 sq. ft. @ 10,000 B. t. u. per sq. ft. average	5,600,000	chiefly radiant
14 combination tubes, 392 sq. ft. @ 5,000 B. t. u. per sq. ft. average	1,960,000	chiefly convection
20 convection tubes, 560 sq. ft. @ 5,000 B. t. u. per sq. ft. average	2,800,000	convection only
Total	23,800,000	

This indicates a total of roughly 80 per cent. of the heat input entering the oil as radiant heat, and such high average rates of transfer must of necessity be dependent on a most even heat distribution, which in our judgment can best be secured by controlled radiant heat.

[Note.—The papers by A. E. Nash and John Primrose were discussed together. For discussion, see page 457.]

Use of Open Radiant Heat in Tube Stills

By John Primrose,* New York, N. Y.

(New York Meeting, February, 1928)

Tube stills having demonstrated their usefulness for refining operations, the later developments in their design have been in the direction of improved thermal efficiency. The earlier designs operated with low furnace temperatures and large volumes of furnace gas because the fuel was burned with much excess air. It was quite possible to provide sufficient heating surface to lower the temperature of the flue gas to within 150° of the temperature of the inlet oil, or when inlet-oil temperatures were high to have the flue gas escape at 300° or 350° F. by using the heat remaining in the flue gas from the still to preheat the air supplied for combustion. But even so, the thermal efficiency was low because of the large quantity of air used for combustion.

The large quantity of excess air was required to burn the fuel in the furnace at a temperature low enough to prevent overheating the furnace walls and overheating of the oil. Supplying heat to the tubes of the heating surface at a rate beyond the capabilities of the oil to absorb, except with a considerable difference between the temperature of the inside of the tube and oil passing through, would result in overheating the tubes and the oil in contact with them. For these reasons it was very necessary in the older types of tube stills to burn the fuel with large quantities of excess air, resulting in low thermal efficiency despite the low flue-gas temperature.

Neglecting loss by radiation, the thermal efficiency could be improved only by burning the fuel with less excess air, but it was necessary to accomplish this without upsetting the furnace temperature conditions existing when large quantities of excess air were used. There are several methods of bringing this about, such as controlling the furnace temperature by returning a proportion of the flue gas to the furnace, or by exposing direct to the fire a heat-absorbing surface so located and proportioned that sufficient heat will be absorbed by radiation to prevent excessive furnace temperatures.

Special Design for Tube Still

A very workable design which accomplishes this purpose is shown by Figs. 1–3. These figures show a tube still that has been in successful

* Foster Wheeler Corpn.

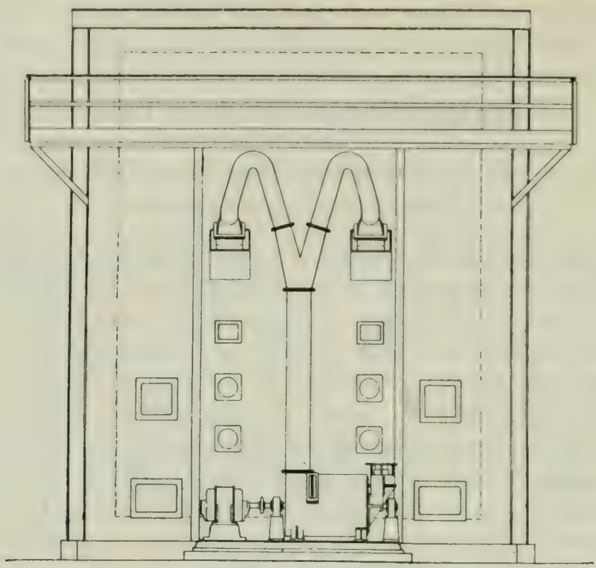


FIG. 1.—FRONT OF TUBE STILL, SHOWING EQUIPMENT FOR BURNING POWDERED COAL AND LOCATION OF BURNERS.

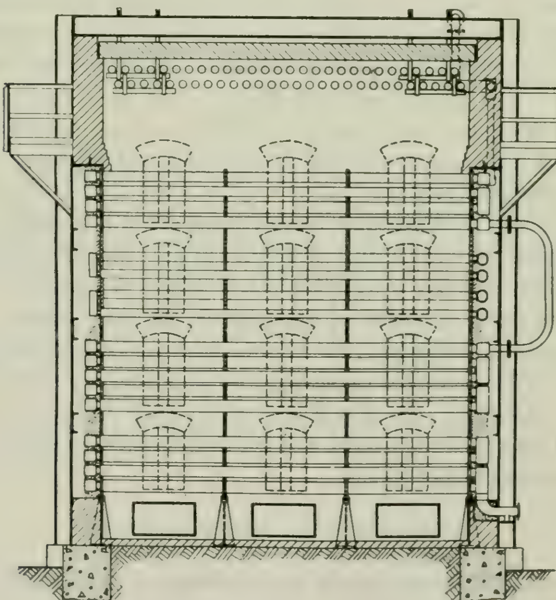


FIG. 2.—CROSS-SECTION OF TUBE STILL.

operation for over six months, so that actual plant-operating data are available. This particular installation is equipped to burn either powdered coal or fuel oil, and data are available showing the operating conditions with both kinds of fuel. The general features of construction are clearly shown, but special notice should be given to the large furnace volume and the extent and location of the radiant-heat absorbing surface, because all of these features have an important bearing on the operating results obtained.

Flame impingement must be avoided to prevent overheating the tubes of a steam boiler, although water absorbs heat much more readily than oil. Thus it is of utmost importance to avoid flame impingement

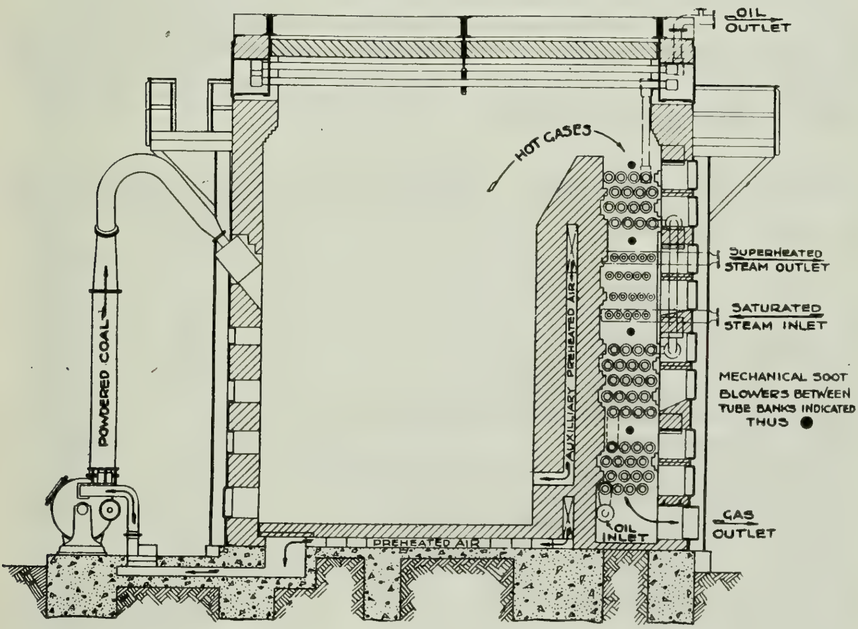


FIG. 3.—SECTION THROUGH TUBE STILL, SHOWING ARRANGEMENT OF RADIANT AND CONVECTION HEATING SURFACES AND EQUIPMENT FOR BURNING POWDERED COAL.

on the heating surface of an oil still. The surface directly exposed to the furnace in the still illustrated is located beyond the reach of any flame, and is directly in the path of the hot furnace gas passing to the flue. The rate at which this surface absorbs heat by radiation from the fire is dependent on the heat liberated per unit of volume of the furnace and the distance of the surface from the source of heat. These features can readily be provided for in the design, and it is fortunate that sufficient surface to insure a moderate furnace temperature can be provided in the desired location over a furnace of sufficient volume while maintaining rational over-all dimensions and simplicity of construction.

All combustion is complete, leaving only transparent gases of combustion, well below the top of the combustion chamber. All of the heating surface is easily visible through openings in the walls of the setting, because combustion has been completed and only transparent gases, even when burning coal, come in contact with the tubes of the heating surface. This is very desirable in any kind of still operation. As the furnace has been cooled by the heat absorbed by radiation, the temperature of these transparent gases of combustion has been lowered to an extent that they can safely be brought into intimate and direct contact with tubes and the remaining available heat absorbed by convection. This is done by locating the tubes of the convection bank behind the bridge wall where they are protected against radiation from the fire and flame impingement. Locating these tubes in a restricted space and forcing the gases of combustion to pass over them at a high rate of speed, without baffles, insures the greatest heat absorption with the least amount of surface.

Table 1.—*Data Taken during Tube-still Operation on Pennsylvania Crude*

Fuel Burned B. t. u. Value of fuel	Coal 12,800/Lb.	Fuel Oil 136,000/Gal.
Throughput—42 gal. bbl. per day	1900	1830
Temperature of oil entering tube still, °F	290	270
Temperature of oil leaving tube still, °F	760	770
Temperature of oil leaving convection bank, °F	465	450
Vaporization, per cent. of throughput as shown by bottoms plus excess vaporization	90.0	90.0
Temperature of gases entering convection surface, °F	1120	1010
Temperature of gases leaving convection surface, °F	355	385
Temperature of steam leaving superheater, °F	660	670
Pressure of steam entering superheater (moisture 2 per cent.)	26	24
Weight of steam used per hour	1390	1600
CO_2 in furnace, per cent	15.0	13.0
CO_2 in flue, per cent	14.3	11.5
Fuel consumption, pounds or gallons per hour	980	100 gal.
Estimated B. t. u. per hour absorbed in convection surface	3,740,000	3,580,000
absorbed in steam	290,000	365,000
absorbed in convection bank (total)	4,030,000	3,945,000
absorbed in radiant surface	6,600,000	6,780,000
absorbed in unit (total)	10,630,000	10,725,000
Estimated thermal efficiency, per cent	84.8	79.0
Transfer, B. t. u. per hr. per sq. ft. inside surface to oil in convection section	4250	4070
Transfer, B. t. u. per hr. per sq. ft. inside surface to oil in radiant section	6680	6870
Total inside surface in convection section		880 sq. ft.
Total inside surface in radiant section		987 sq. ft.

With tube stills of this construction the maintenance cost is extremely low, because no part of the heating surface is worked beyond its limit of endurance. The tube still illustrated has been operated for over six months at times with an outlet temperature in the oil of 800° F., and there is no evidence anywhere of overheating. There have been no replacements and no carbon deposition in the tubes, so that there is no reason to suppose that even the hottest tubes will not last indefinitely.

The data in Table 1, taken during plant operation, will show how well the design of the tube still illustrated has met the somewhat unusual and difficult requirements of efficient tube-still operation.

DISCUSSION

E. P. Kiehl,* Philadelphia, Pa. (written discussion).—My experience has indicated that radiant heat-absorbing surface may be advantageously used in oil stills without the necessity of shielding the tubes, even to the extent of burning the fuel in a muffle. Very satisfactory results are being obtained by exposing a portion of the heating surface of a pipe still directly to the open radiant heat of the flame and setting. It is essential, however, as stated by Mr. Nash, to separate the radiant heat surface from the convection heat surface in order to prevent both jobs being done on the same heating surface.

The absorption of heat by convection is seldom distributed as uniformly as the radiant heat, because it is difficult to spread the flow of hot gases uniformly over the heating surface. This results in zones of high heat concentration and if rapid radiant heat absorption is added, the conditions become too severe for present materials of construction and failure results.

A furnace of the type illustrated by Mr. Primrose shows a suitable arrangement. The radiant heat surface is placed in the roof of the furnace and the convection surface behind the bridgewall. I have records of operation of such a still in which the rate of heat transfer in the lower row of roof tubes was continuously 13,000 B. t. u. per hr. per sq. ft. of external tube surface installed, or approximately 25,000 B. t. u. per sq. ft. of external tube surface exposed to direct radiation from the furnace.

The Primrose furnace has the advantage that no special or expensive refractories are required and the tube arrangement can be made very orderly, or as the author expresses it, "it is a very workable design." The furnace is equally well adapted to burn powdered coal, fuel oil or gas, which is a very important consideration in refinery practice.

W. Trinks,† Pittsburgh, Pa. (written discussion).—Mr. Nash rightly dispels the recent notion that recirculation of flue gases is the only economical means for uniform heat transfer in oil stills of the tubular type. I consider that radiation is very much shielded in a carborundum furnace, because the carborundum presents what we call in engineering a radiation jump. Even if the muffle were infinitely thin, the radiation jump would divide by two the heat radiated by the flame. The heat is prevented from escaping quickly and is shoved farther along the combustion chamber. If a muffle of constant thickness will not produce the desired effect, it is even possible to make the muffle thick near the hot end, and to perforate it near the cool end, to permit escape of more radiant heat there. Nevertheless the design of Mr. Nash is based upon sound principles of heat transfer.

---

* Power Engineer, Atlantic Refining Co.

† Professor of Mechanical Engineering, Carnegie Institute of Technology.

A disadvantage of the Primrose type furnace lies in the excessive heat loss which is caused by the very large heat-dissipating surface of the big combustion chamber. This heat loss depresses the thermal efficiency of the still. The tube still under discussion seems to share this fault.

A very interesting feature of the Foster Wheeler still lies in the arrangement and location of the steam superheater. From an examination of Fig. 3 (page 455) it will be noticed that the steam superheater is located at a high level, that is to say, above a large number of oil-heating tubes. This arrangement is beneficial in at least one respect. It furnishes heat of a rather low temperature to the incoming oil and heats the latter quite slowly. Heavy oil has the property of picking up heat rather quickly from the tube, while preserving a cold core. If the tube is very hot, the cracking of the oil in conjunction with the high temperature causes coke to form at the tube surface, while the oil in the center of the tube is still stone cold.

When the oil has reached the tubes above the superheater, it is doubtless fluid enough to prevent this cold core; it can absorb heat more quickly. This action can be made more certain by reducing the diameter of the oil tubes above the superheater, for the purpose of feeding the oil through the higher tubes faster and absorbing heat at a greater rate without overheating the tubes, and without an unduly great pressure drop.

J. Primrose, New York, N. Y. (written discussion).—Mr. Nash directs attention to many advantages of radiant heat and quite properly so, because of late years much progress has been made in utilizing heat radiated from furnaces. Water-cooled furnace walls and superheaters absorbing heat radiated directly from the fire are common practice in steam boilers today but only a few years ago were unheard of. Even now there exists considerable difference of opinion about materials to be used and how best to arrange them. It is therefore not surprising that those responsible for the design of apparatus for heating petroleum products have not always utilized radiant heat to the best advantage. Tube stills today, however, compare most favorably with the best steam boiler practice in design and thermal efficiency—largely because of the more complete utilization of radiant heat.

It is now well known that sufficient heat-absorbing surface exposed directly to a source of heat, such as a fire, has a cooling effect in proportion to the heat absorbed. The rate of heat absorption can be accurately calculated as described by Mr. Nash, and is largely controlled by the furnace temperature. It is only necessary, therefore, to supply heating surface enough so that when it is absorbing heat at an allowable rate it will absorb sufficient heat from the fire to reduce the furnace temperature to a point where the allowable rate of heat absorption will not be exceeded. Stated differently, if sufficient heat-absorbing surface is exposed to the fire a predetermined furnace temperature can be realized regardless of what the temperature of combustion might have been if not cooled by the radiant heat absorbed. Thus it is possible to burn the fuel with only sufficient air to insure complete combustion, thereby realizing the maximum furnace efficiency. It is, of course, essential that combustion be complete. This can be accomplished as Mr. Nash describes in a closely confined space or in a space of sufficient volume to insure complete combustion of all gases produced from the fuel before they are cooled by contact with heat-absorbing surface. It is also essential to guard against the flame striking against any heat-absorbing surface, otherwise heat would be concentrated at the point of contact with disastrous results to the heating surface. Flame impingement is to be guarded against rather than contact with gases produced by combustion, as Mr. Nash suggests, particularly when the gases are produced in a furnace cooled by surface absorbing radiant heat.

Surface exposed to a fire absorbs heat rays only on the side exposed to the fire. This is distributed somewhat by the mass of metal in the tube, but the heat absorbed by the side exposed to the fire is many times the heat absorbed by the opposite side of the tube. This feature must be carefully considered in locating and designing radiant heat-absorbing surface, if uniform heating of the fluid passing through the tube is to be maintained. In the design of Mr. Nash's furnace the radiant heat-absorbing tubes over the furnace are credited with an average heat absorption by radiation of 20,000 heat units per sq. ft. for the total surface of both the exposed and opposite side of the tube. There is, therefore, the possibility of the absorption rate being higher on the exposed side of these tubes than is desirable when heating a fluid such as oil, suggesting the advisability of providing more radiant heat-absorbing surface. It is obviously desirable to accomplish the purpose with a minimum of surface.

J. S. Alcorn,* Philadelphia, Pa. (written discussion).—The operating data sheet from Mr. Primrose's paper shows a rather low B. t. u. value for fuel oil, but owing to the lack of a fuel analysis no check can be made. Any error in the B. t. u. calculation would have a direct bearing on the efficiency figures. The heat transfer per square foot of heating surface is figured on the inside surface of the tubes instead of the outside surface, as is the general practice. This, of course, results in a higher figure for the heat transfer per square foot of heating surface than would be the case if the outside surfaces were used.

While the data sheet gives neither the temperature rise of the oil in the convection section nor the specific heat, I believe some error has been made in taking the temperature of the gases entering this section. The temperature of the gas entering the convection section is given as 1010° F.; the temperature entering the stack as 385° F.; the CO_2 as 11.5 per cent., and the B. t. u. transfer per hour as 3,945,000. Figuring from the heat release it would require a temperature of close to 1600° F. in the gases entering the convection section under the conditions stated to secure a transfer of 3,945,000 B. t. u. per hr. It is possible that the thermocouple taking this temperature was located too close to the tubes and radiated heat to these tubes, thus giving an incorrect reading.

I believe Mr. Primrose is in error when he states, "the rate at which this surface absorbs heat by radiation from the fire is dependent upon the heat liberated per unit of volume of the furnace and the distance of the surface from the source of heat." It has been fairly well demonstrated that in an enclosed chamber the distance of the heat-absorbing surface from the point of generation of the radiant heat has little influence on the heat transfer rate. What difference there is is accounted for by additional loss by radiation through the increased wall surface.

It is, however, of benefit in an open fire furnace to provide a considerable distance between the heat-absorbing surface and the source of heat, in order to provide sufficient time for the combustion reaction to be completed. If the distance is too short, increased difficulty is encountered in keeping the flame from impinging directly on the tubes, in which case the high heat of the gases at the point of impingement, added to the heat of radiation from the surface walls, usually overheats the tubes.

The heat transfer per square foot of tube area in the so-called radiant section given as 6870 B. t. u. per sq. ft. per hr., figuring on the inside surface of the tubes, is considerably below a safe heat transfer rate with the oil at a maximum temperature of 770°. If proper provision is made for maintaining a high velocity of the oil in the tubes, present practice indicates that with uniform heat application the transfer rate can be several times the transfer rate secured by Mr. Primrose without endangering either the oil or the tubes.

* Alcorn Combustion Co.

J. Primrose.—The furnace temperature at the top was taken by several thermocouples arranged along the length of the tube and is fairly accurate. I agree that such measurements are subject to correction for radiation, but under general operating conditions they are not so far off. I have been guilty of estimating the heat transfer from the inside of the tube. It seems to me that that is properly the place to measure the heat transfer as much of the problem is to heat the oil by contact with the heating surface and it is the inside of the heating surface that the oil is in contact with.

I cannot check Mr. Alcorn's figures of the heat absorbed by the convection bank from the temperatures given and the volume of gas as estimated. Of course, the heat absorption in the radiant heat section is an average, as I pointed out in my discussion of Mr. Nash's paper. The exposed side of the tube absorbs heat much more rapidly than the side not exposed, and the lower row in the construction absorbs heat more rapidly than the top row. The maximum rate of heat transfer, therefore, is considerably above the average, and is quite high enough for workable conditions.

R. E. Wilson,* Whiting, Ind.—On page 444 of Mr. Nash's paper it says, "It should be remembered, however, that in a furnace setting the radiant heat is confined within the walls of the furnace, and is reflected and re-radiated from point to point, until ultimately taken up by the heat-absorbing structure, lost either by conduction through the ground and setting, or carried away by the combustion gases." Then he proceeds to draw the conclusion which Mr. Alcorn also drew, that this condition tends to equalize the actual rate of transfer almost regardless of the relative distance between the primary source of heat and the heat-absorbing surface.

I doubt the soundness of that conclusion since we are dealing with re-radiation rather than reflection. The process of re-radiation involves picking up heat at high temperature and re-radiating it at the temperature of the wall. While no loss of heat is involved, there is a very real loss in heat-transferring capacity and in the potential driving force of the heat to get it into the tube. In checking over some operating data on such a unit it was impossible to explain the relatively low heat pick-up until we took into account the factor of re-radiation from the walls at lower temperature.

I think Mr. Trink's discussion is based on the concept of a cold core of oil and a surrounding film that is at cracking temperature. As far as any practical pipe-still operation is concerned, that is impossible, as we are not operating in the region of parallel flow.

A. Mullhaupt, Jr.,† Bradford, Pa.—I recently inspected a pipe still of the Foster Wheeler type, vaporizing 85 per cent. of a daily throughput of 2400 bbl. of crude. As compared to the temperature existing in the furnace of the pipe stills of our cracking plants, and the furnaces under batch stills running crude, the temperature was very low. The pyrometer indicated 1150° F., and the color in the furnace was so dark that it gave the impression that the fire was liable to go out any minute. Apparently, by the proper arrangement of the tubes it is possible to obtain low flame and gas temperatures, which will not injure the oil being processed.

L. A. Mekler, Chicago, Ill.—I have made a few observations to determine the difference in temperature of the furnace as indicated by a thermocouple above the tube coil and the actual furnace temperature as indicated by a Leeds and Northrup optical pyrometer. In a furnace depending primarily on convection this difference was from 100° to 200° F.; the couple above tubes indicating the lower temperature. This difference is due mainly to the so-called shading effect of the tubes of the coil on the thermocouple; this effect will be the greater, the closer the thermocouple is to the

* Standard Oil Co. (Indiana).

† Kendall Refining Co.

tube. When the upper part of the thermocouple, *i. e.*, the part exposed to the radiant heat from the furnace arch, was sighted by the optical pyrometer, the difference between the optical reading on the couple and the optical reading on the walls of the furnace was very small, 20 to 50° F. The furnace temperatures as indicated by the optical pyrometer decreased more or less gradually when sighted on different points starting from the arch of the tube compartment down towards the tube.

A. E. Nash.—Replying to Mr. Kiehl, we believe that provided the radiant heat alone is effective on any particular area, there is little or no danger due to excessive transfer rates. If, as Mr. Kiehl suggested, the high temperature gases are kept from contact with that part of the surface which is taking a high rate of transfer by radiant heat, we think the operation will be successful.

Commenting on Mr. Wilson's suggestion on the intensity of transfer, radiant heat cannot be "lost" after it has left the surface of the carborundum furnace as radiant heat, except, as explained in the paper, by setting losses or by some other minor losses; it must of necessity get into the tubes. It is our thought that the explanation should take into account both the lower rate of transfer from the wall and the relatively greater area of the total setting.

Mr. Primrose also brought out the intensity of transfer rate through the lower part of the tube. There is no question but that the amount of heat input into the tube itself, would be materially higher on the bottom than on the upper part of the tube. It is perhaps made more nearly uniform into the oil by the conductivity of the tube walls. As Mr. Primrose also brought out, the actual contact between the inside surface of the tube and the oil is the true place of transfer. Considering the thickness of the metal in the tube and the high conductivity of that metal, I believe that the action of the tube will be to more or less even out the rate of heat transfer into the oil itself. This is further helped by the radiation or reflection from the roof, and as far as that goes, from the other tubes. I do not know how it could be determined but I believe there would be a difference, but how great that difference is I would not want to make any attempt to guess.

We felt that there was a difference between a localized or a limited high temperature radiant heat and an evenly distributed or as it has been commonly called, a "shielded radiant heat." My thought was this: that to distribute or even out the heat from a localized point such as was used in the illustration, an arc light, is considerably more difficult than to even out the distribution of radiant heat which is already spread over the entire furnace. It is probable that the evening-up action would apply in both cases, but it certainly would have a better start if it had already been spread out over a large area.

There was one further point that Mr. Primrose brought out, namely, the fact that if the tubes which are receiving a high rate of radiant heat are so located that the combustion is completed before the gas has reached them, they will be safe, to use a common word. My thought is this: While you can provide large furnace volumes in order to complete the combustion, there is still the point of necessity of bringing the fuel and air in intimate contact, and in large furnace volumes there is a possibility that that will not be the case. It is possible to have sufficient air available and even sufficient temperatures to complete combustion, but if the air and fuel do not come in contact at the same time this temperature is existent you will not get complete combustion. For that reason, we believe that in a furnace such as illustrated by the carborundum tunnel the gases passing in high velocity through the tunnel must of necessity be in close contact and must of necessity be subjected to a very high temperature. We believe that this insures complete combustion, and we are therefore confident that, having used the carborundum furnace as illustrated, we would get complete combustion. We sometimes question whether in open furnace work complete combustion always is accomplished.

The Recirculating Furnace

By L. A. Mekler,* Chicago, Ill.

(New York Meeting, February, 1928)

The recirculating furnace is primarily a heating apparatus of the convection type in which the heat-absorbing surfaces are heated by a mixture of fresh products of combustion and a portion of the combustion gases that have already given off a part of their heat in their previous passage over the heat-absorbing surfaces.

In its basic conception, the recirculating furnace can be considered as a closed thermal system in which the heat-absorbing surfaces are constantly swept by a fixed quantity of products of combustion at a given initial temperature with the gases being constantly returned to the furnace and reheated before they again enter the heating zone. Gases equal in amount to those produced by the fuel burned to reheat the circulating gases are constantly ejected from the system to the stack.

The recirculating furnace is the most suitable apparatus for heating by convection where low furnace temperatures must be maintained and where only a small portion of the available heat is taken out of the gases, particularly where the maximum allowable furnace temperature is low and where the final temperature of the gases is only a few hundred degrees below their initial temperature. In such cases, recirculation not only provides a method of reducing the rather high combustion temperatures of the fuel when burned without a large amount of excess air, but, by returning to the furnace the heat content of the gases at their final temperature, recovers a large portion of heat that otherwise would have been lost through the stack.

The convection-type oil still is particularly suitable for the application of flue-gas recirculation. In an oil still, the heating of the oil is accomplished by applying to the tube surfaces a given quantity of heat of a certain predetermined quality, usually with the initial temperature of the gases not over 1500° F. as measured by thermocouples placed above the tube bank. To obtain the full benefit of the heating surface of the coil, the final temperature of the gases, after passing over the coil, is kept 200° to 300° higher than the temperature of the incoming oil. This final temperature varies from 500° F. for a topping still with only a slight or no

* Combustion Engineer, Universal Oil Products Co.

heat interchange before the oil enters the still, up to 1100° F. in some cracking stills where the raw-oil feed is used for condensing the high-boiling-point fractions of the oil, and is so preheated to as high as 800° F., as in the Dubbs cracking process.

The total quantity of combustion gases required to accomplish the heating of the oil by convection under such conditions is determined from the equation

$$W_T = \frac{\theta}{Q_1 - Q_2} \tag{1}$$

where W_T = the total weight of combustion gases required
θ = the total convection heat applied to the coil
Q_1 = the heat content, B. t. u. per pound, of the gases at their initial temperature
Q_2 = heat content of the gases at their final temperature.

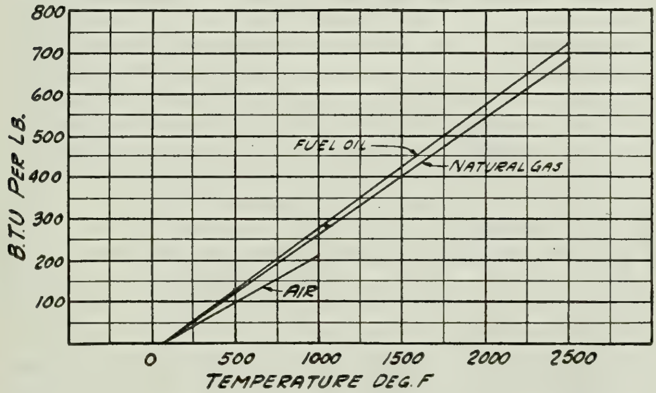


FIG. 1.—AVERAGE HEAT CONTENT OF PRODUCTS OF COMBUSTION AND AIR AT DIFFERENT TEMPERATURES.

Fig. 1 shows the average heat content of the products of combustion at different temperatures. The curves on this figure and the subsequent ones are primarily intended to show the trend rather than the numerical values of the quantities, but the values of Fig. 1 can be used in equation (1) with an accuracy of $\pm$ 5 per cent. for excess air of 25 to 250 per cent.

The first requirement of convection-still operation is the reduction of Q as obtained in the fresh products of combustion to a value corresponding to the maximum allowable furnace temperature. The reduction of Q can be accomplished either by a large amount of excess air used for combustion, the common method when no recirculation is used in a convection-type furnace, or by diluting the heat content of the fresh products with a sufficient amount of returned gases with a heat content of Q_2 to obtain the equivalent of Q_1.

Fig. 2 shows the heat content of fresh products of combustion obtained with different amounts of excess air and air preheat used for combustion,

if no recirculation is used, and illustrates the correlation of excess air, air preheat and the value of Q for different firing conditions.

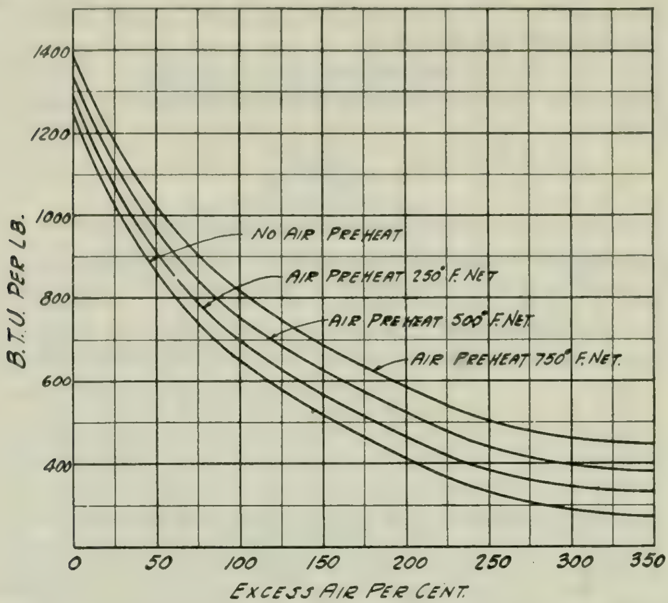


FIG. 2.—HEAT CONTENT OF FRESH PRODUCTS OF COMBUSTION (FUEL OIL) WITH DIFFERENT AMOUNTS OF EXCESS AIR AND AIR PREHEAT.

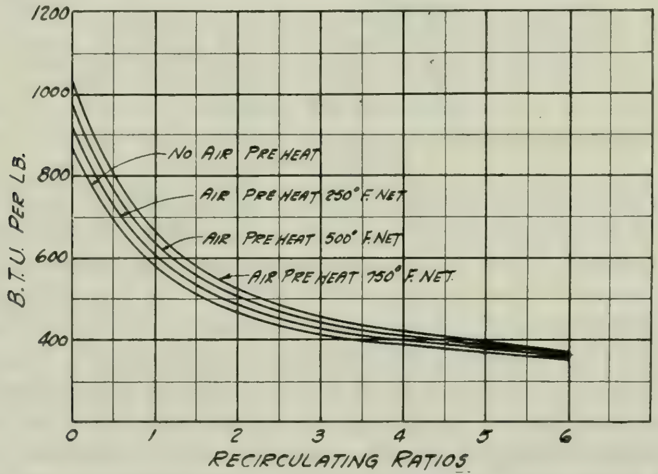


FIG. 3.—HEAT CONTENT OF FRESH PRODUCTS OF COMBUSTION (FUEL OIL) WITH DIFFERENT RECIRCULATING RATIOS. FLUE-GAS TEMPERATURE 1050° F. EXCESS AIR 50 PER CENT.

Fig. 3 shows the modification of the heat content of fresh products of combustion of fuel oil burned with a 50 per cent. excess air, by the admixture of different amounts of flue gases at a temperature of 1050° F.

The recirculating ratio of Fig. 3 is the number of pounds of flue gases mixed with one pound of fresh products of combustion and the values obtained will be true for average operation of the furnace on the Dubbs cracking process.

The curves on Figs. 2 and 3 indicate that the reduction of Q to the value of the maximum allowable furnace temperature can be obtained in several ways. For example, with Q = 390 B. t. u. per pound, this value

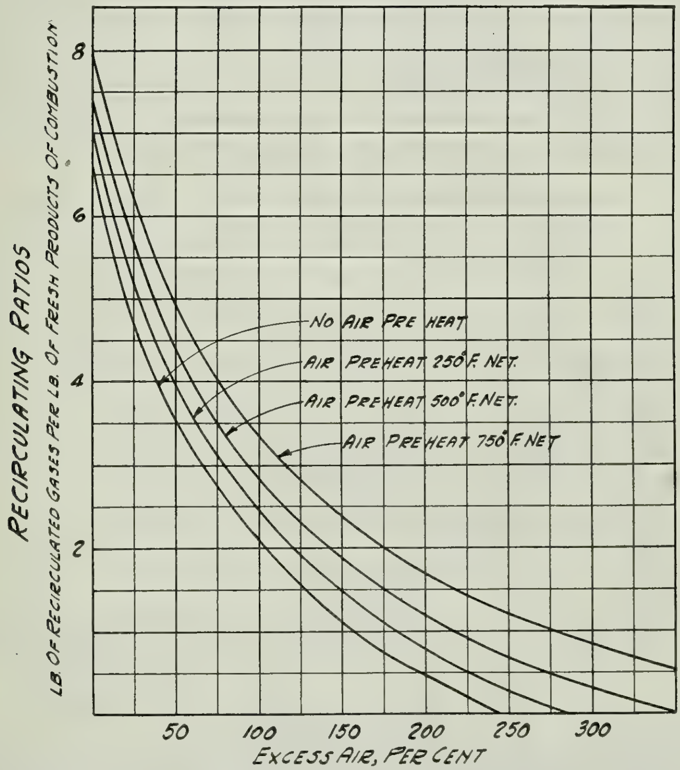


FIG. 4.—RECIRCULATING RATIOS FOR DIFFERENT AMOUNTS OF EXCESS AIR AND NET AIR PREHEAT. MAXIMUM GAS TEMPERATURE 1500° F. FLUE-GAS TEMPERATURE 1050° F.

can be obtained with no air preheat and a recirculating ratio of 4.5; with a recirculating ratio of 5, if 250° F. air preheat is used; with a recirculating ratio of 5.5 if 500° F. air preheat is used; and with a recirculating ratio of 6 if 750° F. air preheat is used. If no recirculation is used, the same value of Q can be obtained by varying the amount of excess air and the air preheat. With no air preheat, an excess air of 215 per cent. will give the necessary value, as will an excess air of 250 per cent. with 250° F. preheat; an excess air of 350 per cent. with 500° F. air preheat and an excess air of approximately 500 per cent. with an air preheat of 750° F.

Figs. 4 and 5 show respectively the different variations that are possible in obtaining 1500° F. maximum furnace temperature with flue-gas temperatures of 1050° F. and 750° F. and different amounts of excess air and air preheat.

The curves of these figures are based on the heat balance in the gases before they give off any heat to the heat-absorbing surface and are the evaluation of equation:[1]

$$R = \frac{W_R}{W_T} = \frac{(Q_c - Q_1)}{(Q_1 - Q_2)} \tag{2}$$

where R = recirculating ratio
W_R = weight of recirculated gases
Q_c = total heat content of fresh products of combustion, and W_T, Q_1 and Q_2 are as in equation (1)

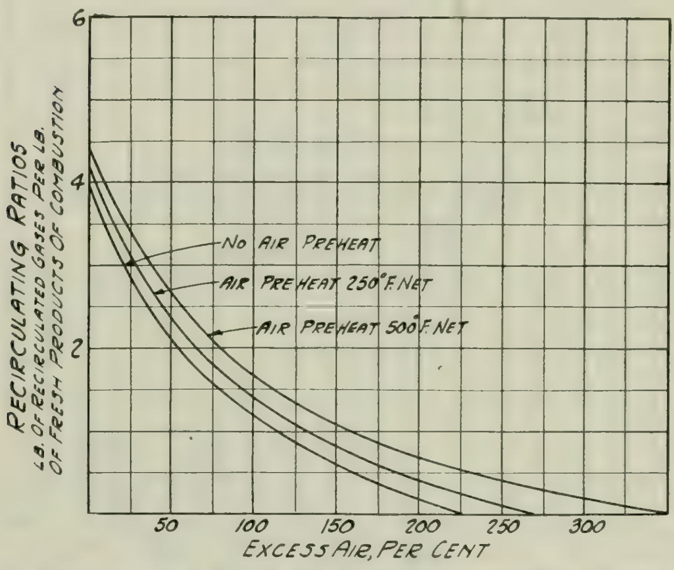


Fig. 5.—Recirculating ratios for different amounts of excess air and net air preheat. Maximum gas temperature 1500° F. Flue-gas temperature 750° F.

From Fig. 4, it is apparent that the same results can be obtained with a 2 to 1 recirculating ratio and 105 per cent. excess air with no air preheat, as with 1 to 1 recirculation, 215 per cent. excess air, and 500° F. air preheat, or with 1 to 1 recirculation ratio, 280 per cent. excess air and 750° F. air preheat. Any other combination within the area bound by the curves of "No air preheat" and "Air preheat 750° F." will give the same operating results. If the flue-gas temperature is 750° F. instead of 1050° F., as assumed for Fig. 4, the recirculating ratios required to obtain 1500°

[1] For derivation of this equation see Appendix 1.

F. furnace temperatures are much lower for the same excess air coefficient. The possible variations are shown on Fig. 5.

The choice of a combination of recirculating ratio, amount of excess air and degree of air preheat should be determined by purely economic considerations such as the cost of fuel and the original operating and maintenance cost of the equipment.

Figs. 6 and 7 show the economic balance of the gross savings obtained with different recirculating ratios and air preheat of the corresponding amounts of excess air required to bring down the values of Q to that of the desired maximum gas temperature (Figs. 4 and 5). Fig. 6 shows that with a flue-gas temperature of 750° F. and a maximum gas temperature of

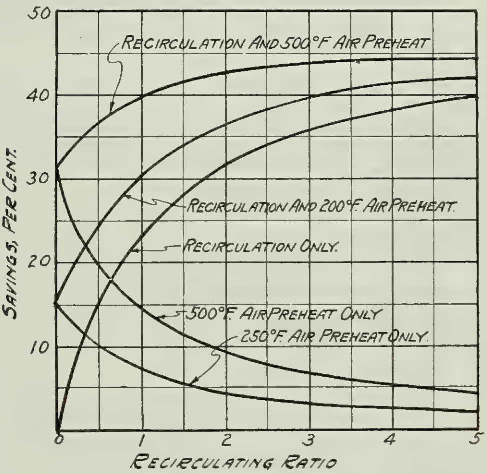


Fig. 6.—Possible savings with recirculation and air preheat. Maximum gas temperature 1500° F. Flue-gas temperature 750° F.

1500° F., fuel has to be very expensive in order to justify recirculation of over 2 to 1. From this point the curves of savings begin to flatten out very rapidly. An increase of the recirculating ratio from 2 to 3 gives an increased saving of only 4 per cent.; from 3 to 4 gives 2.5 per cent., and from 4 to 5, less than 2 per cent. With a flue-gas temperature of 1050° F. and the same maximum gas temperature, recirculating ratios above 3 to 1 cease to be economical (Fig. 7).

The savings due to air preheat drop off even at a greater rate with increase of the recirculating ratio, particularly with the higher air preheat temperatures. Without recirculation, a 750° F. air preheat with 1050° F. flue gases gives a saving of 45 per cent. of the total fuel used (Fig. 7). With a recirculating ratio of 2 to 1, the savings due to air preheat drop to slightly over 15 per cent. With the increase of the recirculating ratio and the consequent decrease of the amount of fuel, the excess air, and

therefore the total amount of air used, the savings due to preheating of the air, are constantly decreased until they are only slightly over 5 per cent. with a recirculating ratio of 5 to 1.

The savings from the combined recirculation and air preheat per additional unit of recirculation decrease even faster than the savings from recirculation alone, when the recirculating ratio is increased. From Fig. 6, with an air preheat of 250° F., recirculating ratios above 1.5 to 1 show

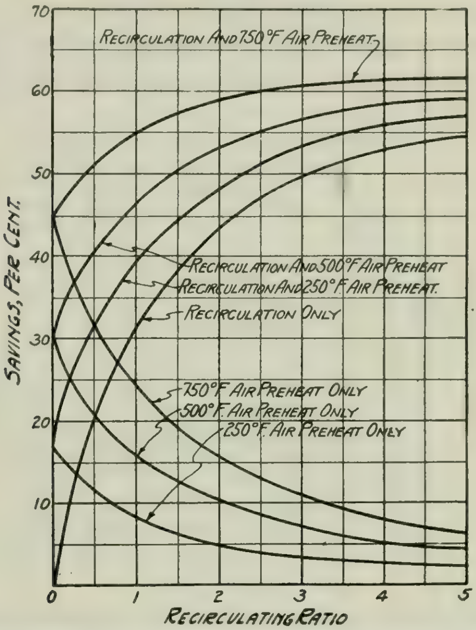


FIG. 7.—POSSIBLE SAVINGS WITH RECIRCULATION AND AIR PREHEAT. MAXIMUM GAS TEMPERATURE 1500° F. FLUE-GAS TEMPERATURE 1050° F.

very little increased savings for each additional unit of recirculation. With preheats of 500° F., a recirculating ratio of 1 to 1 will be the most economical. Table 1 shows the possible savings with the different combinations of recirculation, and air preheat with a Dubbs furnace for 8,000,000 B. t. u. convection heat load and losses of 500,000 B. t. u.[2] Table 2 shows the effects of recirculation on the Dubbs process as obtained at different plants. In actual practice with the Dubbs process, the most balanced installation is obtained with recirculating ratios of between 2.5 to 1 and 3 to 1, and air preheats of from 400° to 500° F., as is indicated on Fig. 7.

The mechanical design of the recirculating furnace deserves serious consideration. The method of withdrawing the flue gases from the

[2] See Appendix 2 for method of calculation.

TABLE 1.—*Oil Consumption and Fuel Efficiency of Still under Different Operating Conditions*

8,000,000 B. t. u. Convection Input in the Oil; 500,000 B. t. u. Loss in Furnace

	Fuel Required, Pounds	Heat Supplied by Fuel, Million B. t. u.	Excess Air, Per Cent.	CO_2	Loss of Heat in Flue Gases, Million B. t. u.	Oil Heating Efficiency
No recirculation......... No recuperation.........	1320	24.8	230	4.8	16.3	32.2
Recuperation only....... Air pre-heat 800° F., net	727	13.7	500	2.8	5.2	58.3
Recirculation only....... 4.62:1 no air preheat	602	11.3	25	12.4	2.8	70.6
Recirculation 1:1 .... Air preheat 650° F. net	717	13.5	204	5.1	5.00	59.2
Recirculation 2.5:1 ..... Air preheat 300° F. net..	649	12.2	91	8.3	3.7	65.5
Recirculation 3:1........ Air preheat 500° F. net..	580	10.9	85	8.5	2.4	73.4

system and their mixing with fresh products of combustion will greatly determine the combustion efficiency of the fuel burned and the temperature distribution in the furnace. The gases to be recirculated must be so withdrawn that the draft distribution in the heating chamber is not affected by the change in recirculating ratio, that is the speed of the recirculating fan, or even by the complete failure of the fan—a common occurrence with most of the older types of fans.

The whole recirculating system should be placed on a by-pass to allow repairs to fan and connecting flues while the furnace is in operation.

The recirculated gases must be introduced into the furnace at a point beyond the zone of actual combustion. CO_2 is one of the best fire extinguishers. If large ratios of recirculation and, consequently, small amounts of excess air are used in the furnace, the flue gases will tend to retard the process of combustion on their contact with the fresh gases. This will result in considerable losses from incomplete combustion of the fuel in the combustion chamber and the complete arrest of combustion of the gases when they strike the comparatively cool heat-absorbing surfaces of the still. Up to 5 per cent. CO was found in the furnace gases of one installation where flue gases came in contact with the fresh gases before combustion was complete. If a comparatively large excess of air is used and high flue-gas temperatures are maintained, the retardation of combustion is only temporary and there is a possibility of secondary combustion after a more intimate mixing of the partly burned fuel and the air admitted. Quite often the damage to the recirculating fan and air preheater attributed to corrosion from the sulfur of the gases and the

TABLE 2.—*Effect of Recirculation and Air Preheat on Still Operation*

90—4-in. Tube Still

	Fans On	Fans Off
R. O., bbl. per hr	77.5	58.3
Fuel—gas cu. ft. per hr	17,480	20,733
Fuel ratio, oil equivalent, per cent. of R. O	5.16	8.16
Furnace above tubes °F	1407	1495
Furnace below tubes °F	970	973
Fan discharge, °F	831	
Preheater discharge, °F	352	172
Stack	583	807
Per cent. CO_2	9.0	4.0
O_2	4.5	15.0
Furnace efficiency, calculated	69.16	44.

62—4-in. Tube Still

	Fans Off	Fans On	Fans On*
R. O., bbl. per hr	35.6	39.6	52.1
Fuel, bbls. per hr	2.34	2.12	3.15
Fuel ratio, per cent. of R. O	6.57	5.38	6.03
Furnace above tubes, °F	1568	1565	1560
Furnace below tubes, °F	969	985	1059
CO_2	6	11.5	6.5

72—5-in. Tube Still

	Fans On	Fans Off
R. O., bbl. per hr	76.5	57.4
Furnace above tubes, °F	1500	1565
Furnace below tubes, °F	1030	1010
CO_2	9.2	3.8
Fuel Ratio, per cent. of R. O	5.42	8.67

* Pre-heater by-passed, to allow for larger throughput unit operated beyond the capacity of the recirculating system.

water leaks from the water-cooled fan bearings is due to secondary combustion within the fan and preheater itself because of much more thorough mixing of the gases and the air on their passing through the fan and the preheater.

The method of mixing of the flue gases with the fresh products of combustion affects not only the combustion process but the heat distribution within the still as well. The recirculated flue gases are from 450°

to 750° F. cooler than the operating furnace temperature and usually over 1000° F. cooler than the fresh products of combustion. If the mixing of the fresh products of combustion and the recirculated gases is not intimate, the furnace temperatures will differ in the different parts of the still.

Fig. 8 shows the temperature distribution over a tube bank in a recirculating still, with various degrees of intimacy of mixing of the products of combustion with the recirculated gases. With poor mixing the difference was more than 200° F. from the center to the ends. Proper mixing gave a difference of less than 10° F.

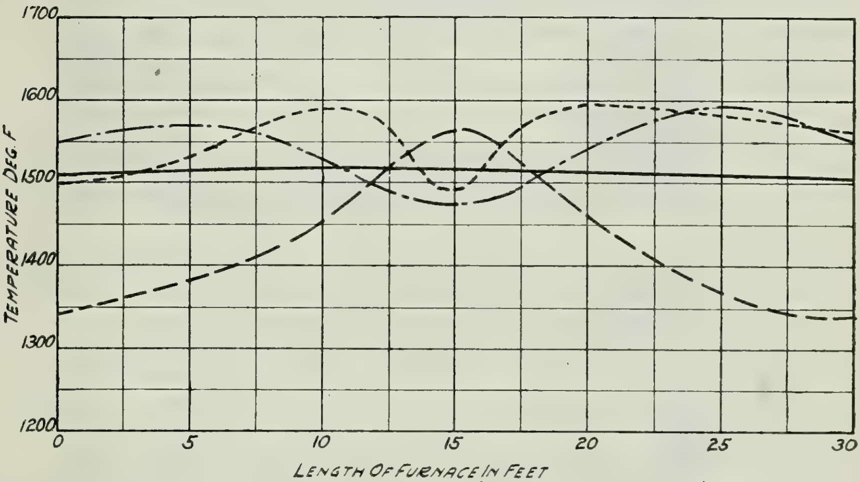


FIG. 8.—EFFECTS OF MIXING FRESH AND RECIRCULATED GASES ON FURNACE TEMPERATURE DISTRIBUTION.

The degree of mixing affects mainly the temperatures above the tube bank. The temperatures below the tube bank are affected by the method of withdrawing the gases from the furnace and the point at which the recirculated gases are taken from the flue.

Fig. 9 shows a good arrangement of withdrawing the flue gases for recirculation. The fan is located between the furnace and the stack, and since the recirculating system is a closed system within itself the failure of the fan does not upset the draft and the temperature distribution along the length of the furnace. This arrangement uses only one fan, which is also an advantage in that the recirculating system is either fully on or off.

Fig. 10 shows a one-fan arrangement in which the flue gases to be recirculated are withdrawn from an end opposite to that acted upon by the stack pull. The disadvantage of this arrangement is the complete disturbance of draft distribution in the furnace with the failure of the

recirculating fan, unless dampers are provided under the tube bank to redistribute the draft along the length of the furnace.

Fig. 11 shows a rather popular arrangement of two fans, each drawing from an opposite end of the furnace with the stack acting either on the center of the furnace as shown, or with one on the end, which is even more common. This arrangement, as that on Fig. 10, has the disadvantage of disturbance of the draft with the failure of either of the fans.

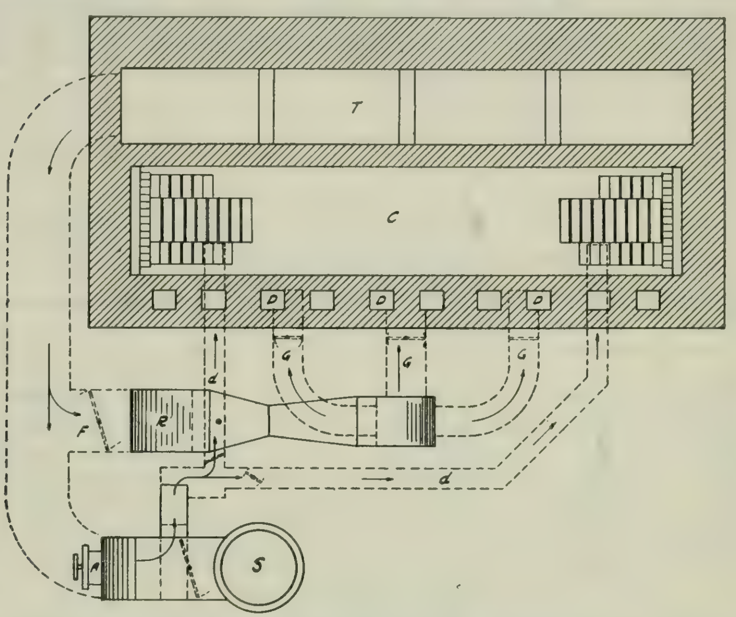


FIG. 9.—SCHEMATIC PLAN OF RECIRCULATED STILL. RECIRCULATING FAN SUCTION BETWEEN FURNACE AND STACK.

T = tube chamber
C = combustion chamber
D = recirculated flue-gas distributor
F = recirculated flue-gas fan intake
G = recirculated flue-gas fan discharge
R = recirculated flue-gas fan
A = cold-air fan
P = air preheater
S = stack
d = preheated air duct

The most common methods of returning the products of combustion to the furnace are shown on Figs. 12 to 15.

Fig. 12, which is a section of the arrangement of Fig. 10, shows a method by which the recirculated flue gases are introduced into the center part of the combustion chamber through an arch and are distributed approximately at right angles to the natural path of the fresh products of combustion. The introduction of such an arch resulted in a much more even distribution of the furnace temperatures than was obtained with

center flue-gas discharge without the arch. The only disadvantage of such an arrangement is that with the fan down considerable excess air

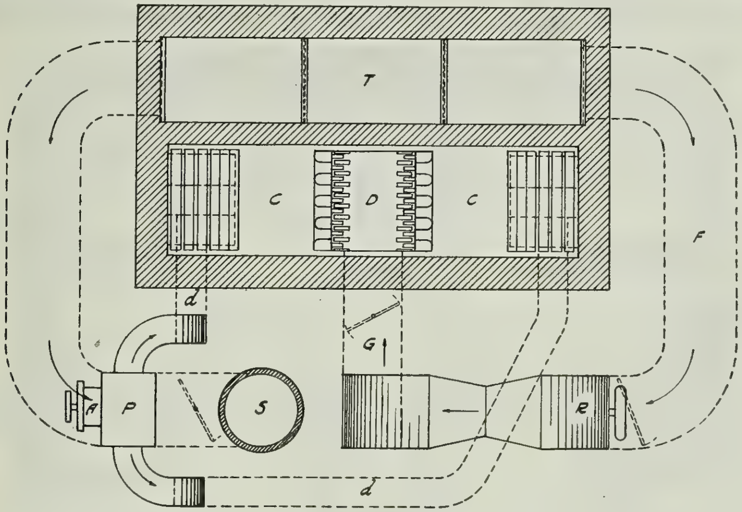


FIG. 10.—SCHEMATIC PLAN OF RECIRCULATING STILL. RECIRCULATING FAN SUCTION ON END OPPOSITE TO THAT ACTED UPON BY THE STACK.

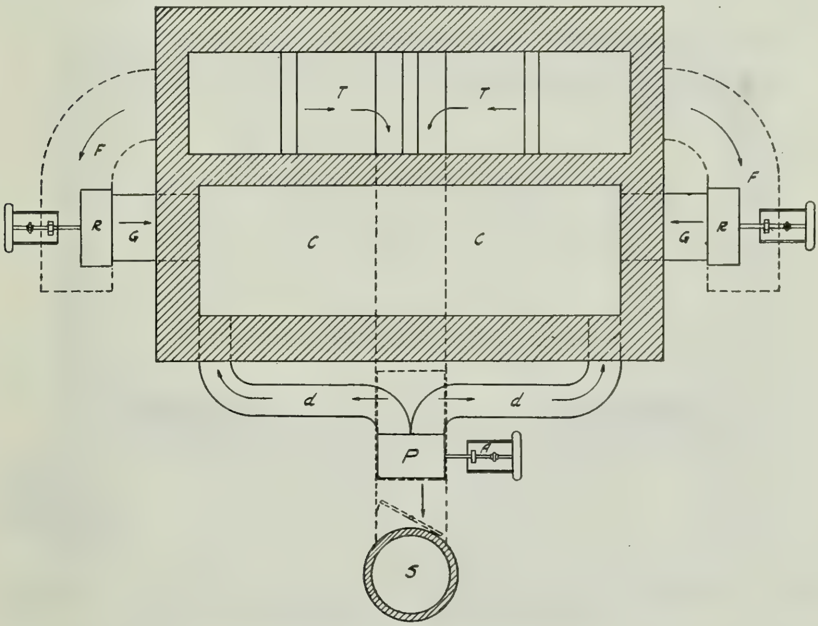


FIG. 11.—SCHEMATIC PLAN OF RECIRCULATED STILL. TWO-FAN ARRANGEMENT.

has to be introduced into the recirculated flue gas duct to obtain an even temperature distribution along the tube bank.

Fig. 13 shows a multiple flue-gas inlet method of mixing and is a cross-section of scheme shown on Fig. 9. Except for rather high construction cost and somewhat weaker wall, this method is preferable to the method

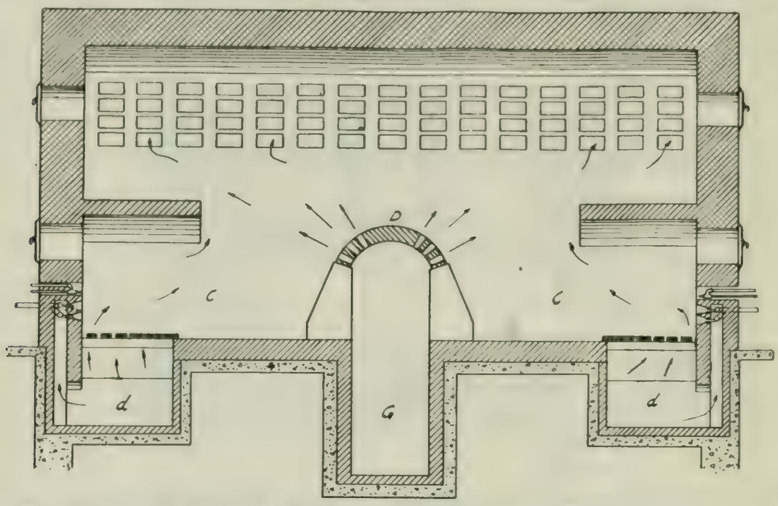


FIG. 12.—SCHEMATIC SECTION OF RECIRCULATING STILL. RECIRCULATED FLUE GAS DISTRIBUTION THROUGH ARCH.

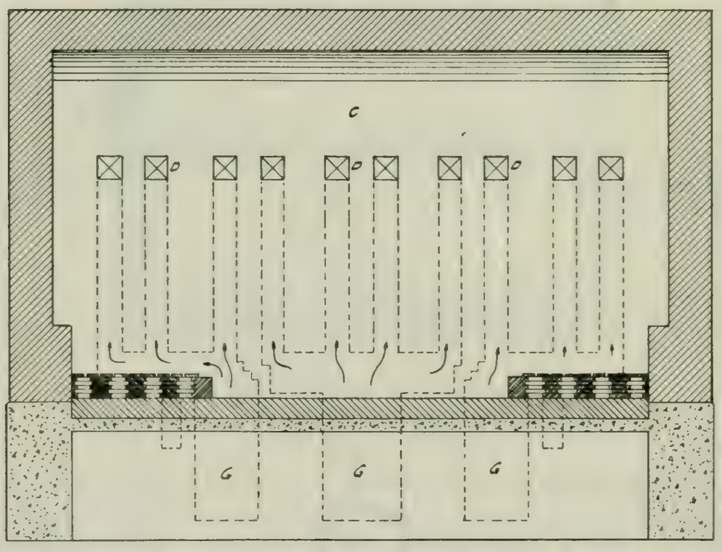


FIG. 13.—SCHEMATIC SECTION OF RECIRCULATING STILL. MULTIPLE WALL FLUE DISCHARGE OF RECIRCULATED FLUE GASES.

shown on Fig. 12. The natural tendency of the cooler gases to descend will produce considerable eddies in the furnace and assist in their mixing with the products of combustion. By manipulating dampers *a*, *b* and *c*,

the amount of the recirculated gases delivered to each discharge flue in the wall can be controlled, and an even temperature distribution much more easily obtained than with the scheme shown in Fig. 1.

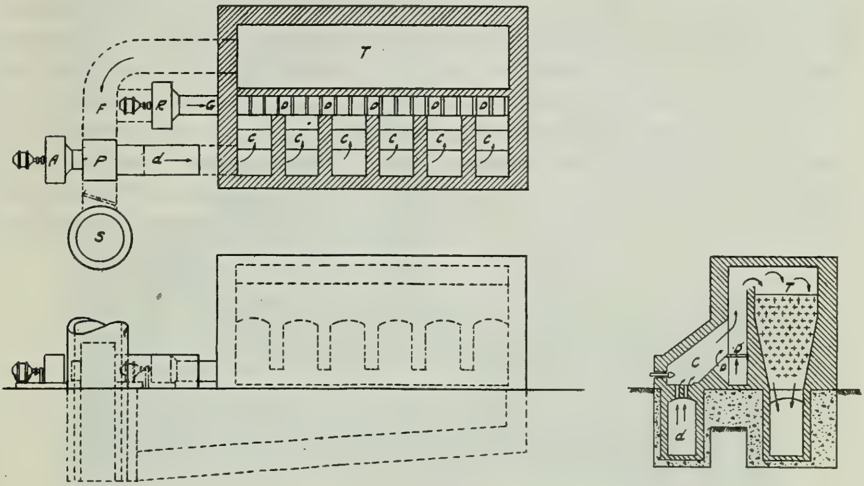


FIG. 14.—SIDE-FIRED RECIRCULATING STILL.

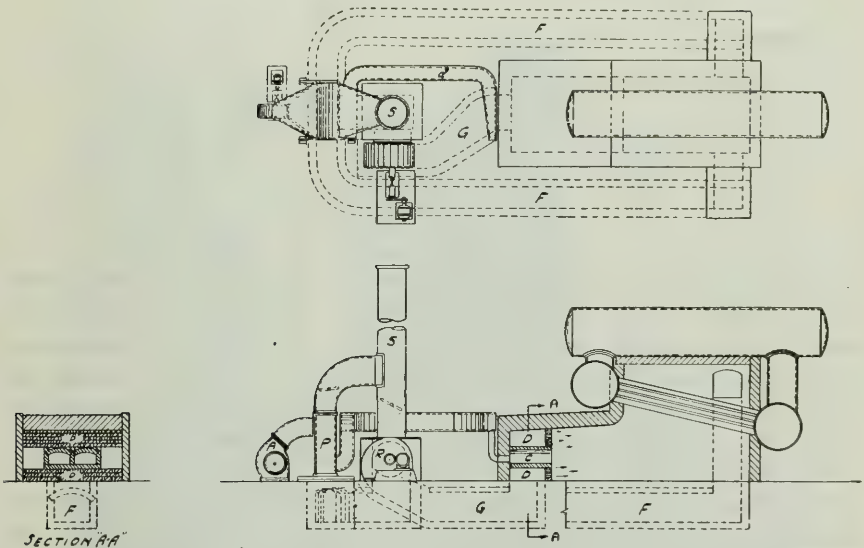


FIG. 15.—SINGLE END-FIRED RECIRCULATING STILL.

Fig. 14 shows the most suitable furnace arrangement for a recirculating convection still. This still is side-fired in a multiplicity of fireboxes, which allows good control of the distribution of the fresh products of

combustion, considerably better than the one obtained with the end-fired furnaces. The recirculated flue gases are withdrawn at one point between the stack and the furnace and are distributed through a tile-covered flue at an angle to the path of the fresh products of combustion, which induces the most thorough mixing. As a secondary consideration, the recirculated products of combustion will act as a protection for the partition wall of the furnace from the radiant heat in the combustion chambers.

Fig. 15 shows a rather novel method of mixing the fresh products of combustion and the recirculated gases. This arrangement not only induces good mixing of the fresh and recirculated gases but reduces the amount of radiant heat that is applied to the brickwork for re-radiation to the exposed tubes of the still.

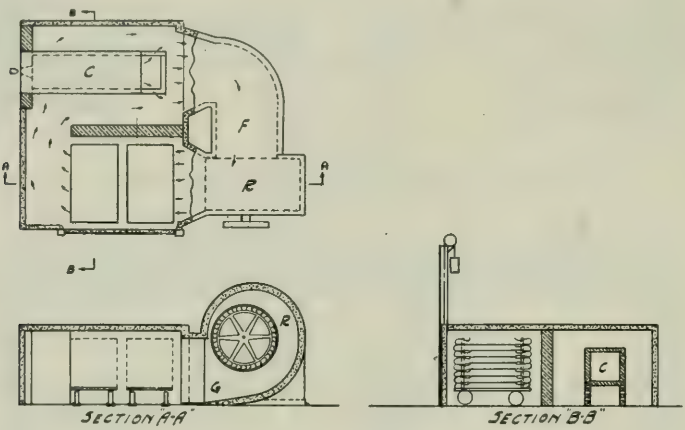


FIG. 16.—RECIRCULATING DRAWING FURNACE.

Fig. 16 illustrates an application of recirculation to industries outside of oil refining, which is quite different from those common to stills. The method consists of drawing the flue gases over a carborundum combustion chamber which radiates a considerable amount of the heat through the carborundum and preheats the recirculated gases to a high temperature before they are actually mixed with the fresh products of combustion. The difference in temperature between the products of combustion and the recirculated gases is made very small; therefore the danger of stratification or channeling of these gases is reduced to a minimum. The scheme shows the combustion chamber on the suction end of the recirculating fan to obtain an intimate mixing of recirculating and fresh gases within the fan itself. The arrangement as shown is applicable only to

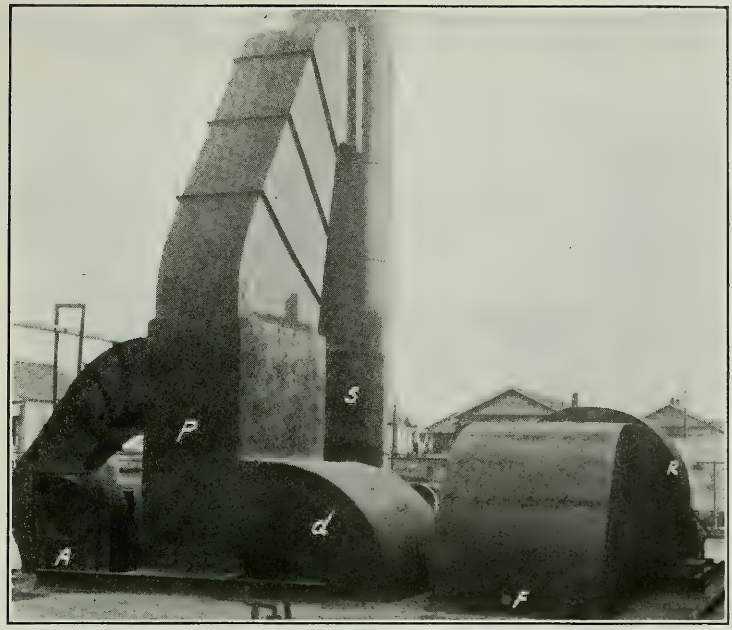


FIG. 17.—RECIRCULATING STILL. GENERAL ARRANGEMENT AS PER FIG. 9.

FIG. 18.—RECIRCULATING STILL. GENERAL ARRANGEMENT AS PER FIGS. 10 AND 12.

low furnace-operating temperatures, usually below 1000° F. For application at higher temperature the combustion chamber is placed on the discharge end of the fan and the final mixing is obtained in a separate mixing chamber, or by means of baffles and checker work in the entrance to the heating chamber itself.

The number of industries using the recirculating furnace, and the number of recirculating furnaces in each of these industries, shows that the recirculating furnace is at present completely out of the experimental

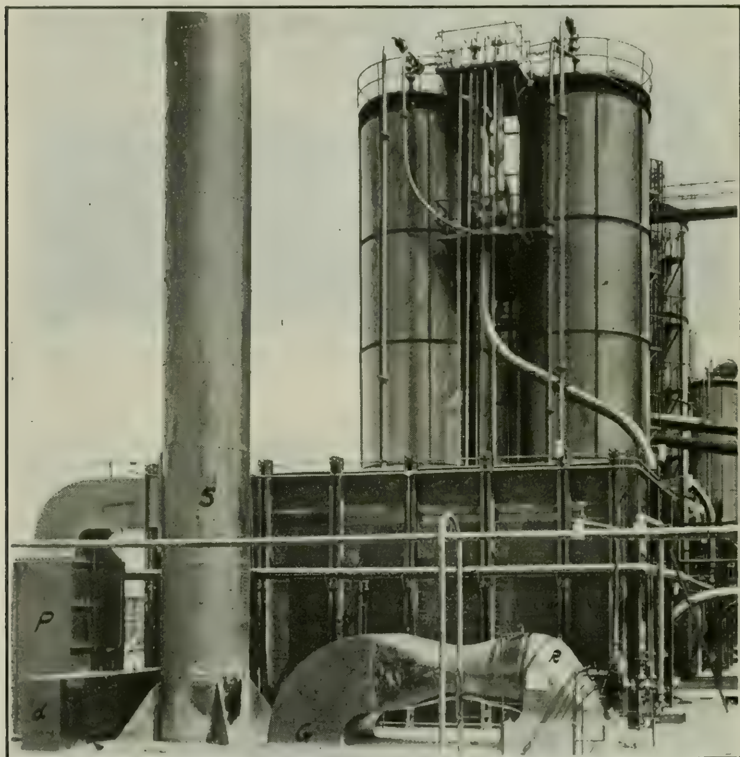


Fig. 19.—Recirculating still. General arrangement as per Figs. 10 and 13.

stage and is gradually emerging from the phase of rapid and quite often radical changes of design and operation. There are a number of manufacturers of hot-gas fans that have at present perfected their fans to a stage where they will be as reliable in operation as any other piece of refinery equipment with moving parts.

The power consumption of the latest designs of fans is very low. An electrically driven recirculating fan which is responsible for a saving of approximately 52 bbl. of fuel per day uses 10 hp. per hour.

The initial cost of recirculating fans is constantly forced down by the newly developed competition.

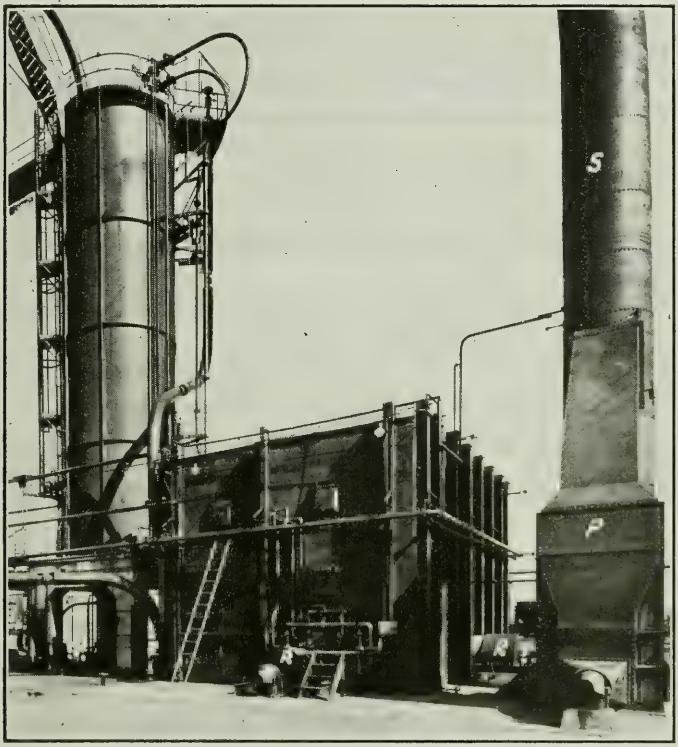


FIG. 20.—RECIRCULATING STILL. MULTIPLE-FAN ARRANGEMENT.

While not a cure-all for the ills of refinery heating, the recirculating furnace, properly designed and equipped, will produce a milder heat application, give larger throughput with the same amount of heating surface, and perform the heating with less fuel and better efficiency than the non-recirculating convection furnace, and in many cases the radiant-heat furnace as well.

Appendix I

Nomenclature

W_T = total weight of gases passing over the heat-absorbing surface, pounds.
F = weight of fuel, pounds.
W_F = weight of fresh products of combustion, pounds.
W_R = weight of recirculated gases, pounds.
W_A = weight of air per 1 lb. of fuel.
Q_c = heat content of fresh products of combustion at their initial temperature, B. t. u. per lb.
Q_1 = heat content of products of combustion at their initial temperature, B. t. u. per lb.
Q_2 = heat content of products of combustion at their final temperature, B. t. u. per lb.
Q_A = heat content of air due to preheat, B. t. u. per lb.
Q_F = heating value of fuel, B. t. u. per lb. = 18,500

$$\underbrace{W_F Q_C}_{\text{Heat in fresh prod. of combustion.}} + \underbrace{W_R Q_2}_{\text{Heat in recirc. gases.}} = \underbrace{W_T Q_1}_{\text{Heat in total gases.}} \qquad (1)$$

$$W_F + W_R = W_T \qquad (2)$$

Substituting the value of W_T

$$W_F Q_C + W_R Q_2 = (W_F + W_R) Q_1$$
$$W_F (Q_C - Q_1) = W_R (Q_1 - Q_2)$$
$$W_R = W_F \frac{(Q_C - Q_1)}{Q_1 - Q_2}$$
$$R = \frac{W_R}{W_F} = \frac{Q_C - Q_1}{Q_1 - Q_2}$$

Appendix II

No Recirculation: No Recuperation

Heat available per pound of gases, cooling from 1500° to 1050° F. (From Fig. 1).

$$389 - 261 = 128 \text{ B. t. u.}$$

Total weight of gases required to deliver to tube surfaces, 8,000,000 B. t. u.

$$8{,}000{,}000 \div 128 = 62{,}500 \text{ lb.}$$

Heat content of gases before passing over the tube surfaces,

$$389 \times 62{,}500 = 24{,}300{,}000 \text{ B. t. u.}$$

Total heat required, including 500,000 B. t. u. losses in furnace,

$$24{,}300{,}000 + 500{,}000 = 24{,}800{,}000 \text{ B. t. u.}$$

Weight of fuel required, 24,800,000 ÷ 18,500 = 1320 lb.

Oil heating efficiency, 8,000,000 ÷ 24,800,000 = 32.2 per cent.

Even without air preheat or recirculation, the weight of fuel used is negligible compared to the total weight of gases (1320 ÷ 62,500 = 2.1 per cent.). With recirculation and preheat and the consequent savings in the amount of fuel used, the weight of fuel can be neglected in the calculations, and the weight of air used for combustion can be assumed equal to the weight of the fresh products of combustion. The following calculations were made on this basis:

No Recirculation: Air Preheat, 800° F. *Net*

Heat content of 1 lb. of air at 800° F. preheat = 178 B. t. u. (Fig. 1)

$$\underset{\text{Total heat}}{24{,}800{,}000} = \underset{\text{Heat from fuel}}{F} + \underset{\text{Heat from air preheat}}{62{,}500 \times 178}$$

$$F = 13{,}700{,}000$$

Oil heating efficiency

$$8{,}000{,}000 \div 13{,}700{,}000 = 58.3 \text{ per cent.}$$

Recirculation, 3: 1; *Air Preheat,* 500° F.

Heat content of 1 lb. of air at 500° F. preheat = 109 B. t. u. (Fig. 1)

Weight of recirculated gases,

$$62{,}500 \times \frac{3}{3+1} = 46{,}875 \text{ lb.}$$

Weight of fresh products of combustion = 15,625 lb.

$$\underset{\text{Total heat}}{24{,}800{,}000} = \underset{\text{Heat in fuel}}{F} + 15{,}625 \times 109$$

$$F = 10{,}900{,}000 \text{ B. t. u.}$$

Oil heating efficiency

$$8{,}000{,}000 \div 10{,}900{,}000 = 73.4 \text{ per cent.}$$

DISCUSSION

C. B. Buerger,* Pittsburgh, Pa. (written discussion).—The recirculating furnace as described by Mr. Mekler does show a very appreciable gain in efficiency over a plain old style boiler tube furnace, but to the man who has to pay the cost of construction, and even more to the man who must maintain repairs, it is an abomination. The radiant type of furnace will afford as much in efficiency improvement as the recirculating system, will add nothing to the cost of the original still, and calls for no additional maintenance expenses.

Radiant heat tubes may be assumed to absorb 10,000 B. t. u. per hr. per sq. ft. of surface, if it is desired to maintain a temperature of about 1500° F. before striking the convection tubes. Such a figure may be found in a paper by Peterkin.[1] With this absorption a very small amount of radiant surface will take up more than half the total heat required by the still, permit of a smaller convection heat section, good economies, and simple construction.

---

* General Manager, Manufacturing Department, Gulf Refining Co.

[1] A. G. Peterkin, Jr.: Pipe Still Distillation, A. P. I. *Bull.* (1928) **9,** No. 7.

Comparing the first column of Mr. Mekler's Table 2 with a typical cracking still heating furnace of approximately the same capacity and of radiant heat tube design, we find in the case of this latter the following figures:

Temperature of fire, °F	2,540
Temperature in the convection tubes, °F	1,510
Fuel gas, cu. ft. per hr	13,560
Radiant surface projected area, sq. ft	175
Total area of radiant surface, sq. ft	550
Heat absorbed by radiant surface, B. t. u. per 24 hr	5,300,000
Rate of heat absorption, B. t. u. per sq. ft	9,636

Such a small amount of surface can readily be installed in a fire box even smaller than the firebox of Mr. Mekler's drawings without adding anything to the cost of the total heating surface. The efficiencies would probably be very similar to those shown in Mr. Mekler's design.

D. G. Brandt,* New York, N. Y.—An important consideration in the operation of a furnace such as described by Mr. Mekler is the atmosphere in the fire box. If the recirculation ratio is low, the excess air required to maintain proper dilution produces an oxidizing atmosphere which harms the heating surface. The excess air also increases the chances of secondary combustion. In our designs we attempt to use only sufficient air for good combustion and then recirculate sufficient flue gas to maintain the desired fire box temperature.

E. P. Kiehl,† Philadelphia, Pa. (written discussion).—There are certain industrial processes, the nature of which makes it necessary to rely on the transfer of heat from fuel by convection only at relatively low temperatures, and in such cases recirculation of the flue gas affords a means of conserving fuel.

In the light of present knowledge, however, such a method of heat transfer is neither necessary nor desirable in petroleum refining practice. By proper arrangement of the heating surface, advantage may be taken of the relatively high efficiency obtainable by direct radiant heat transfer combined with convection heat transfer and such equipment is now in daily use, both for crude running and cracking operations, giving actual operating furnace efficiency of close to 80 per cent.

With such an arrangement, the fans and ducts required for recirculation are eliminated. The fact that the recirculation fans and ducts are apt to be sources of trouble in spite of advances in the art, is substantiated by the following quotation from Mr. Mekler's paper, "The whole recirculating system should be placed on a by-pass to allow repairs to fan and connecting flues while the furnace is in operation."

* Cities Service Co.

† Power Engineer, Atlantic Refining Co.

Chapter XI. Refinery Control

Physical Control of Refinery Processes

By Luis de Florez,* New York, N. Y.

(New York Meeting, February, 1928)

The successful control of any operation, whether industrial, military, or purely physical, is fundamentally dependent upon the same elements: (1) The securing of accurate and pertinent information concerning the factors involved in the operation; (2) Correct interpretation of their relationship as affecting future results; (3) Efficient means for effecting changes in the factors governing the operation to shape the result.

The analogy which exists in the control of operations in these widely differing fields of action is of utmost interest, and in considering the physical control of a process, the realization of its existence permits a clearer conception of the steps required to achieve results and aids in formulating the problems to be met.

Let us imagine, for instance, the requirements for successfully conducting a business. It is evident that the first requisite lies in obtaining continuous and reliable information concerning the functioning of its various branches and in detecting, with the least possible delay, any tendency of change in their functions; next, in correctly analyzing this information by comparison with past records, showing the relation of the particular business to general conditions in the trade; and finally, in employing means for counteracting any unfavorable change in general conditions, or compensating for its effects by an appropriate action.

Likewise, in military operations, the success in carrying out a plan lies primarily in the maintenance of proper intelligence and communication service, which furnishes information as to the disposition of forces; in correct analysis of the ascertained position, guided by fundamental knowledge of tactics; and finally, on the efficient carrying out of orders and effecting corrective movements.

In the physical operation of a process, such as for example in cracking, our information is obtained by pressure and temperature instruments, etc., which permit us to visualize existing conditions under which the operation is being carried out. The information at hand is then analyzed and certain conclusions arrived at as to the results which will be obtained under the observed conditions. If this analysis should indicate, in the

* Consulting Engineer.

light of past experience, that an unfavorable result will be obtained, certain conditions of operation are altered until the desired results are assured.

In the physical control of a refining process we must rely on experience for the choice of information and its interpretation. Each type of process has its characteristics, and the data required and its bearing on the result will, obviously, be individual to the process in question. Likewise, the means and methods of effecting corrections present different problems in each case and the choice of the most favorable procedure to carry out its action must vary with the circumstances.

There are, however, some general considerations which govern the choice of the variables which we have to indicate the action of equipment and on which we base the conclusions which will result in the necessity of making corrective changes. These general considerations also apply to the choice of means or variables with which to obtain the regulation required.

Two Functions of a Control Scheme

There are two main functions to be performed in a scheme for control; one consists of measuring certain operating conditions and detecting their change; the other consists of applying corrective changes. These two functions, one of indication and the other of regulation, are generally found to be independent, and in a given process, a number of ways may present themselves for carrying out either function.

The choice between the various ways of carrying out these functions and their last analysis, are governed by a factor of time and a factor of simplicity. It is obvious that when obtaining a reading or in effecting a correction, a certain time must elapse between the occurrence of the change and the appearance of its effect in the process. It is equally obvious that the desirable variable to utilize for control would be the one in which this time factor is reduced to a minimum.

As an illustration of this, let us consider the result of a process whose ultimate object is the making of a certain quality and quantity of product. It is evident that, if we could control a process on the final results, it would be the simplest way to operate. From the point of view of operating control, however, examination of the product, whether periodical or continuous, is wholly inadequate to serve the purpose, since an appreciable time must elapse between the occurrence of a change and the detection of its effect in the product itself. The examination of the product indicates only past accomplishment and can serve only to confirm the fact that the apparatus has, or has not, been operated correctly during a period of time which is past and beyond recall. It cannot serve as a guide for the future, but only for judgment of the past.

Indication for control, therefore, must be based on some variable encountered at a step in the process in advance of the finished product, and record a condition which is intimately connected with the result, changes in which may permit a timely corrective action. On the other hand, as the desired indication is "advanced into the process," away from the final result, the more it will be complicated by other secondary variables which affect the product, and the more complicated will become the interpretation of its relation to the product, since other variables, although less important, will have to be considered in the analysis of the effect on the ultimate result. The choice of the variable for indication, therefore, must be a compromise between its factor of time and its factor of simplicity.

Relative Usefulness of Control Information

In a cracking operation in which our information is obtained by means of pressure gages, thermometers, level indicators, etc., placed at various points of the apparatus, it is obvious that we can obtain an almost unlimited amount of information by multiplying the number of instruments. This information, however, is not all of equal importance from the point of view of control, since many of the readings simply denote that parts of the apparatus, or auxiliary equipment, are functioning. We have learned that, in cracking, the product will be materially affected by the pressure and temperature in the system and that, if we rely on the maintenance of this pressure and temperature, favorable results will follow. The readings of pressure and temperature anticipate the final result, since they are practically instantaneous and are, therefore, useful in control. They do not represent the whole story however, since other secondary variables must be taken into account, but they present the best compromise between the factors of time and simplicity. Thus we may have on the control board readings of steam pressure, fuel supply, condenser water, etc., which merely denote that the apparatus can function and which do not directly affect the quality or the quantity of the product. On the other hand, the variations in pressure and temperature, which are also made to read on the control board, are carefully watched. We might conceivably dispense with the first class of readings, which are only of general interest, but we could not run the apparatus without specific information concerning the pressure and temperature, which may be considered indicating control factors.

The relative usefulness of information in the operation of a process is of immense importance, and constitutes a study in itself, specific not only to each process but each apparatus developed to carry it out. The primary requisite for control is evidently to choose the variable with which to operate. Skill in operation and technical knowledge must be relied upon to apply this pertinent information to obtain desired results.

The considerations governing the choice between different possible methods of applying corrective changes present a similar aspect. The effect of variations in the process should be prompt and should have an important effect on the product. Again, we have the necessity of compromising between the factor of time and the factor of simplicity, for usually, as we approach nearer to the direct effect on the product, we have combined with it the effect of secondary variables which complicate its action.

If we consider, for instance, the control of temperature at the top of a tower, it is evident that this might be varied by changing the tower radiation by means of air passages and dampers, or by varying the supply of reflux. Both of these methods are possible, but the effect of the first would not be realized for an appreciable period of time, while the effect of the latter, particularly if the reflux is at a low temperature, is to rapidly and quantitatively vary the temperature at a desired point, to cause the desired result.

It is obvious that the second method of control is more appropriate since it has a more direct effect and, further, has the advantage that, from a point of view of simplicity, its action is very close to the result. The secondary variables which complicate its action are only the quality of the reflux and its temperature.

Ideal Control Scheme

The ideal control scheme would be one where a single variable would give the desired indication of the result and a single variable regulated to effect corrections. In the rare instances where this is possible the problem of control is enormously simplified and can be accomplished by simple means. In practice, however, this condition is seldom encountered but it can be approximated, and one of the chief problems in working out a control scheme lies in simulating this condition as far as possible.

As an illustration, we might consider a cracking furnace where fuel is admitted to a number of burners, where the temperature of the outlet of the coil has been found to be the proper indicating control and the rate of firing the regulating control. The fireman, in this case, is given an indicating temperature gage and a recorder. He has a fuel line which is maintained at a higher pressure than the burners and has a series of valves operating these burners. As the temperature rises he cuts the fire and vice versa. The success of this firing will depend on the accuracy of the reading of the pyrometer and the way he effects changes. Should the pyrometer point become coked during the operation, obviously he will be given a false reading and lose control of his apparatus. Should he operate the burners individually, effecting his corrections at four or five points, it will be difficult for him to make accurate changes. On

the other hand, should the flow to the still vary, or the pressure in the fuel main fluctuate, he will have to contend with disturbing elements over which he has no control. It is, therefore, necessary to devise some means whereby he may be given the proper facilities to maintain control of the furnace, and assume the responsibility for its actions.

The pyrometer couple in coil heaters need not, necessarily, be placed at the outlet, but can be placed at some intermediate point which can be found by trial. A reading at this point may be somewhat lower than the desired one, but if its relation to the desired reading be constant, an equally useful and true indication is assured. Likewise, handling of individual burners may be eliminated, assuming, of course, that provision is made to proportion the air for combustion, by the use of a master valve to control the fuel to all burners, using the individual valves on these burners simply to distribute the heat in the fire box, thus a modification of the control fuel valve will effect all burners equally, and maintain approximately even conditions in the fire box under all rates of firing. The flow to the coil may be maintained constant by metering the charge through the control house or by the speed of the charging pump and the fuel main may also be maintained at constant pressure by the use of a reducing valve on the line.

As a matter of fact, in many instances, it is desirable to substitute a reducing valve for the master valve serving all the burners and provide a gage on the burner header. The fireman may then definitely effect increments of pressure which determine the flow of fuel, without contending with the inaccuracies which may be due to even slight fluctuations in the main, or those due to handling a valve by adjusting the position of the stem to make corrections. His regulating control of the temperature of the furnace is essentially the pressure on the burner header, which bears a more direct relation to the temperature at the outlet than the position of the stem on the master valve. The control of the furnace is thus effected by observing the reading of a pyrometer, which bears a definite and constant relation to the outlet temperature, and making changes on the reducing valve which will be reflected by increments in the pressure gages on the burner header.

Regulation by Secondary Control of Greatest Influence

In a more complete apparatus the matter of reducing the number of variables is obviously more difficult, and it becomes necessary to subordinate secondary regulating controls, in order to effect regulation with the one which has the greatest influence on the operation.

In this connection, let us consider the operation of a simple topping unit where the crude oil is pumped to and heated in a coil, separation of the various fractions made in a separating chamber and a fractionating tower, and the products from the tower condensed in the usual manner.

We are primarily interested in extracting the maximum amount of gasoline from the crude, producing a tower bottoms of proper flash, let us say "gas oil," and a residual bottoms of reasonably uniform quality. These separations depend primarily on the amount of heat imparted to the oil and the cooling effect in the separating chamber and the tower. The cooling effect on the chamber is largely dependent on radiation and evaporation, while the cooling effect in the tower, although dependent on radiation and evaporation, is more affected by the reflux pumped back to control the quality of the overhead product. The main disturbing elements are, obviously, the variable radiation and the inaccuracies due to handling the equipment.

If we consider that the overhead from the tower is the primary product and that the quantity and quality of this product determines the success of the operation, it will be evident that the temperature at the top of the tower will constitute the control indicator to determine the quality of the product, and that the quantity of overhead obtained from the apparatus will be largely dependent on the heat input to the tower which will constitute another indicating control. It is also evident that the variation of these factors, to obtain proper control, must be limited to obtain a useful result and their regulation must be related. The heat input to the tower is, obviously, the most important variable and will dominate the control of the temperature at the head of the tower.

Leaving out the effect of a reboiling coil, which may be used in the tower to strip the bottoms, we then become concerned more essentially with the quantity and temperature of the liquid and vapors leaving the coil, which is the source of heat.

Uniform Input of Heat

The uniform input of heat into the tower is of utmost importance. To insure this, the flow of charging stock through the coil must be maintained constant and may be done by metering the charge in a suitable manner, and the temperature at the outlet of the coil must be maintained within as close a limit as possible; in other words, the rate of flow through the coil and rate of firing must be maintained in relation to each other and theoretically, they should both remain constant. This, of course, is not possible, since variations must take place and one or the other factor must be made a variable to effect regulation in order to approximate the ideal conditions and compensate for changes beyond control.

It has generally been found more desirable to alter the rate of firing and maintain the flow constant, as this method of operation gives regulation with the least general disturbance. The regulation of temperature, maintaining the flow constant, can then be effected by the fireman in a similar manner to that previously described, and this means of regulation

can be made responsible for the over-all result after other secondary controls have been adjusted to the rate of firing. The constant changes in atmospheric conditions and other factors necessitate a secondary regulation on the tower, which will require varying the amount of reflux within a limited range, to control its outlet temperature. This variable, however, should be utilized as little as possible and if stress is laid on the uniformity of input of heat to the tower, better fractionation will be accomplished and a greater capacity will be obtained. It is unreasonable to expect that tower regulation can compensate for major variations in heat input and, in many cases, failure to hold the temperature of the top of the tower may be traced to this fact.

If the temperature at the top of the tower be maintained accurately in spite of fluctuations of heat input, a considerable disturbance will ensue in the tower, caused by the large variation in reflux, which will affect the accuracy of fractionation and tend to reduce the capacity.

The foregoing examples are, to say the least, elementary, but they are cited in an attempt to illustrate the type of consideration which must be given to a problem of control, and to suggest a method of approach.

In refinery practice it is not always a simple matter to make a choice of variables, either for indication or control, since their effectiveness may be reduced by design, operating methods, or the combination of parasitic variations of auxiliary equipment.

Chief Requirements for Successful Control

Surveying the chief requirements for the successful control of equipment we may say that they depend primarily on correct design, because it is in design that the greatest results can be achieved in eliminating disturbing variables, and in turning a difficult control problem into a simple one; it depends on the careful and systematic elimination of variations in auxiliary conditions; it depends on the proper choice of variables for both indication and regulation and upon the choice of the best possible balance between the factors of time and simplicity; it depends on adequate indicating and regulating equipment; and last, but not least, it depends on the realization that accurate control means greater returns and that some sacrifices are warranted to obtain it.

In general, apparatus to carry out a certain process must be so designed as to make control possible, and further, the method of operation chosen must be such that the control features are fully capitalized. It is, too, often possible, by skill of operation, to make up for certain defects in design, but this operating skill, obviously, should be employed to obtain maximum results and not to overcome avoidable faults. The matter of control is usually given a good deal of consideration with regard to the disposition of equipment, valves, etc., although not always in the

right direction, and such consideration is often encumbered by customs initiated in obsolete apparatus. Improvements in control are almost invariably possible, in practically all types of refining equipment, if this feature is emphasized and the limitations of instruments is taken into consideration as well as those of the apparatus.

The largest part of refining practice deals with heat treatments and almost all the other factors encountered, such as pressure, etc., result from heating the stock to be refined. It is not surprising, therefore, that in almost every case, regulation of the application of heat is the most important factor in effecting control and is usually of such importance that other variables, encountered in the carrying out of the operation, may be generally considered secondary and subordinated to it.

The regulation of flow of fluid through a system is of prime importance in continuous processing, but it differs in its application from that of control of heat input, in that it is not necessary to utilize its variation to the same extent to compensate for the changes.

Equipment required for constant flow, such as constant volume pumps or meters, has not proved entirely satisfactory and there is much room for improvement in this field. For lack of a better means, the use of pumps in tandem is often desirable, since the high-pressure pump can be made to operate on a comparatively small pressure differential, reducing the slip and permitting more accurate stroking. This is, obviously, a crude approximation of the desired result and in the future, doubtless, pumps will be supplied with governors on the output in much the same manner that a steam engine is supplied with a governor for speed.

Of the many variables which have to be contended with in the operation of a process, the effect of many are unavoidable. There are some, however, which complicate the problems of control and which could be eliminated if sufficient importance were attached to its accomplishment. Probably the worst offender in this is variable steam pressure, which is encountered in almost every refinery.

Variable Steam Pressure

In most cases, the charging pumps in refinery equipment are operated by steam and, needless to say, variations in steam pressure cause fluctuations which have to be corrected either by hand or by such devices as may be used for this purpose. It is evident that fluctuations in steam mains are undesirable and it can hardly be said that they are caused voluntarily. It is almost universally true, however, that pressure variations occur at various periods during the day in a refinery, and that they are particularly severe in winter time. They can be eliminated by the proper use of reducing valves but, in many instances, insufficient drop in pressure between the main line and the charging pumps defeats the cor-

rective action. In this connection, it is sometimes useful to substitute a reducing valve for the throttle valve on the pump, which permits the valve to operate under greater pressure differential, since the low pressure side is on the steam chest proper and its use permits setting up a definite and constant pressure on the pistons.

There is probably no portion of a refinery which is more overloaded than the steam plant, since equipment is increased from time to time, building up load on the boiler plant little by little, until it finally results in sufficient shortage of steam to cause fluctuations in the mains. These fluctuations are multiplied by the ratio of the steam to the oil cylinders, and operations, which would normally be stable and uniform, are rendered troublesome.

It should be clearly borne in mind that when putting in expensive additions to equipment, adequate steam supply will permit the new equipment to produce better returns by the avoidance of fluctuations. An overloaded boiler plant invariably means poor control.

Refinery Fuel

Another source of trouble, which appears to be common, lies in the fact that a refinery is usually required to burn whatever fuel oil happens to be available and, in some plants, even sludge fuel is mixed with the fuel oil and burned under the stills. Variations in fire will often result in appreciable decrease in capacity and quality of products, and it should be a question of serious consideration whether a better grade of fuel would not pay, at least in some of the more delicate operations, in view of the improvement in control. Probably the least trouble from poor fuel oil would come by burning it under the boilers if a little excess capacity were available to absorb fluctuations.

Automatic Control Devices

Automatic devices to effect control will, undoubtedly, relieve hand operation more and more in the future. The use of these devices will require the same consideration as that which should be given in facilitating hand control. They must be, of course, capable of a wide effective range but we should endeavor to limit their action to the smallest possible variations. It must be borne in mind that any regulating control that is working disturbs the operation of the whole, and that best results are invariably obtained from apparatus when it is in balance and requires no adjustment. Perhaps the most important function of an automatic device should be to find this balance quickly and maintain it with the least effort.

The function of an automatic device is, essentially, to reproduce, if not to improve, human action and, in many cases, the detail of its action

is closely parallel. It has, of course, the advantage that its operation is continuous and that nothing save failure can disturb its appointed method of doing its work. It has no other interest, beyond that for which it is intended, and may combine, in its effect, recognition of several changes in the apparatus, always interpreting and counteracting them in the same way.

A great deal of knowledge exists in the physical principles which underlie instruments and their action, and the suspicion with which instruments of automatic devices have been looked upon is warranted only by the fact that many times instruments are improperly used or not developed to operate under conditions imposed. A clearer realization of the purpose for which they are intended will bring about the development of far more suitable instrument equipment. A large part of the problem of fostering this development is incumbent on the refiner.

Most refinery operations can be carried out with four general types of automatic devices; temperature control, flow control, level control and pressure control. A great deal of work has already been done on temperature control and this problem appears to have been solved for the present. Some satisfactory flow control and level control devices have been developed but their use is not yet as extensive, and, although these are, comparatively speaking, of less importance, they will be required more and more in the future. Many existing pressure devices are very satisfactory for certain classes of work, but some new types are required to perform the duties of expansion valves with more accuracy and reliability and be capable of operating under high temperatures. It is expected that apparatus of this character will be available shortly for commercial installation.

The control of equipment is largely based on the transfer of motion at a distance, and many of the devices at present in use have employed air, steam, liquid and electricity as motive power to transfer these motions. Those who have operated refineries in cold climates would, doubtless, be able to give a vivid description of the troubles attending the use of air and steam; and those who have used hydraulic systems for transmission of power could also recite tales of woe.

Use of Electricity for Remote Control

The solution of most remote control lies in the use of electricity, since cables can be properly safeguarded, and if an installation be properly made, it is capable of more reliability than other systems. The difficulty in connection with electric transmission of motion has been due chiefly to failure of motive power and contacts, and complicated mechanisms to carry out the required motions. Power failures, however, may be eliminated by making provision for auxiliary generators, underground conduits

and armored cables. Contact difficulties can be practically eliminated by the use of alternating current and better relays.

With regard to the mechanism for the transmission of motion, it is interesting to note that an electrical system, which has been in existence for some 14 years, has been adapted to some of the uses suggested above and is available and can be developed to adapt itself to almost innumerable applications. The particular system comprises a pair of motors connected with four wires and energized with single phase, alternating current. The armatures of both motors are always in phase and the motion of one will affect the motion of the other within remarkable accuracy. These motors, developed by the General Electric Co., were first put into use on the Panama Canal to reproduce the position of the locks, on a small scale. They have since been used in connection with the fire control equipment on battleships and engine room telegraphs and various types of indicators.

When it is realized that a slight motion of the armature of one of these motors can be transmitted to any number of points, at practically any distance simultaneously and accurately, we can well imagine the possibilities that such transmission will have in refinery equipment. They can be used to operate valves in remote places and record their position, transmit level indications and pressure readings at a distance without danger of fouling in lines, and doubtless the adoption of this principle, in time will effect material changes in design by giving more freedom in position of control valves and equipment, which must now be placed in such manner that they have to be handled manually.

In the foregoing, an attempt has been made to generalize on physical control of equipment, but obviously, the subject is so broad that only the salient features can be touched. It really represents a new phase in refinery engineering, and the study and application of the principles of control will go a long way toward making available the economies which have been sought in the design of modern equipment. This phase of refinery engineering must be taken seriously, it must be realized that it is distinctly a specialty, that reasonable concession should be given to improvement of control when undertaking new designs, and efforts should be made to modify existing operations and equipment to make adequate control possible. There is no field of refinery technology which offers more interest, and none which offers so much return to the refiner for moderate expenditures.

DISCUSSION

In response to a question from Walter Miller, Ponca City, Okla., the author stated:

"The torque of the twin motors depends on the size of the motor so that their use is not limited to indicating. For example, they may be used to operate the starting and stopping on a valve-actuated motor, the actual position of this valve being indicated by the position of the control motor."

Technological Control of Refinery Processes

By Ernest B. Phillips* and Albert E. Miller,† New York, N. Y.

(New York Meeting, February, 1928)

The title assigned to this paper permits a discussion of one of the most interesting chapters in the history of the American petroleum industry. Nature was kind to man when she prepared crude oil for him in commercial quantities in the hills of Northwestern Pennsylvania. Most of the refining operations we are now accustomed to apply were either not needed or had been carried out by earth processes ages ago. Such technology as was applied dealt with the physical separation of the valuable components in the crude oil and intermediate products and did not need more than mild refining treatments to bring them to marketable quality.

The pioneer refiners were concerned principally with distilling, dewaxing and decolorizing operations. The products produced were limited in number and the uses to which they could be put were few. Natural products from the very high grade crudes, then plentiful, supplied the domestic demand and no other markets were open. As time passed, other producing fields were discovered and crude oils of lower natural quality were made available. To refine these grades to a quality expected by buyers, refinery practice had to be changed and new methods found. At the same time the accidental discovery that crude residues could be cracked by dry distillation at atmospheric pressure to produce a much larger amount of lamp oil than had been customary, opened a new vista for the industry. Export kerosene soon became the leading revenue product for all refiners and considerable new technic was added to refinery practice. High sulfur crude oils from Ohio next made their appearance, causing the development of the first commercial desulfurizing process, the sodium plumbite treating method for "sour" lamp oil stocks and the application of fine earth for the removal of "flock." Some improvements in methods of handling lubricating oils and cylinder stock fractions of crude were worked out, but in general, it can be said that the closing decade of the last century found the industry in a stabilized condition.

Typical refinery operations of 1900 were simple and were conducted with the single purpose of producing as much export kerosene as possible. Light naphthas and fuel oils were a drug on the market and every means

* Chief Chemist, Sinclair Refining Co.

† Process Chemist, Sinclair Refining Co.

was taken to hold the yields of these commodities to the lowest possible figures. Crudes were run for test bottoms, the overhead being cut for crude naphtha over to 52°, water white stock 52° to 42°, prime white stock 42° to 38°, gas oil 38° to 32°, wax distillate 32° down to the desired residue, with steam refined stock, flux or coke as the still residue. Intermediate stocks were all steamstilled for such light naphthas as were wanted and the steamstill bottoms were included in the prime white stock. The water white stock was steamstilled to test and distillate fractions sent back to crude naphtha for redistillation. The prime white stock, plus the naphtha bottoms, was steamstilled to test and the almost worthless distillate, known as gas naphtha, was lost in the best possible way, usually by running it down some convenient river. Gas oil was sold as such and lubricating oil stocks were finished in ways suitable for producing engine oils and cylinder stocks.

Such laboratory control of quality of products as was carried out in the early days was confined to pure physical testing of commercial products. Lamp oils received the most attention and lubricating oils somewhat less. The laboratory staffs were headed by men from the refinery organizations and testers were recruited from the neighborhood. These men were trained simply to know whether a product met current specifications or not, and at that point their responsibilities ended. No thought was given to yields and no equipment was supplied for determining whether quality could be made better. In fact, the laboratory staff was usually regarded as a nuisance by the operating department. Practically no attention was paid to the cost of producing certain products and very little accurate accounting was carried out.

With the turn of the century, however, developments within the petroleum industry came rapidly. The prolific Texas and Mid-Continent fields poured forth their floods of oil and ways had to be devised for handling these crudes possessed of entirely different characteristics from those which had hitherto been the only crudes available. Plants in operation in 1900 were in no shape to run the heavy oil from the Spindletop field. A new equipment had to be created before suitable refineries could be built. For the first time in the history of the American petroleum industry the laboratory staffs were called upon to furnish data from which refinery units could be designed. This resulted in the construction of experimental laboratories and in the installation of semi-commercial equipment. How well these first experimental plants fulfilled their destiny can be seen in the records of the older Gulf Coast refineries. Such operations as reruns over lye and acid-treating test lubricating oil distillates to obtain finished products do not seem unusual to us now, but they marked distinct advances when first practiced.

During this same period, 1905 to 1910, the first pipe lines from Oklahoma to the Gulf were being laid and mixed paraffin base crudes were

being delivered to refineries in large quantities. These oils were not considered fit for the production of lubricating oil and were to a large extent only skimmed to produce light oils and the residues sold as fuel oils. The controlling factor in the world markets was still the production of export kerosene and all operations had to be planned with that fact in view. Gasolines, naphthas and fuel oils were by-products and could never be made of primary importance.

The above gives a very good picture of the condition of the American oil industry up to about 1912 or shortly before the outbreak of the world war. Practically every oil refinery in the country had been built on designs sanctioned by long use. Almost over night, export kerosene was dethroned as the world's most important petroleum product and the hitherto practically worthless naphthas became the sources of greatest revenue. The industry was faced with the necessity of executing an "about-face" in the system of handling crude oil. Whereas before, good management had consisted of squeezing into export kerosene every drop of distillate possible, the new conditions demanded the maximum production of motor fuel.

From 1910 to the close of the war, little change in refinery equipment or operations was witnessed, but a new force was beginning to make itself felt. Wise managers had begun to fill their laboratory and engineering staffs with young technically trained men. These men brought with them a new viewpoint into the industry. They were chemists and engineers who were unhampered by the traditions of the industry and who were loath to believe anything was being done in the best manner or at the least cost possible. The newcomers did not receive a cordial welcome from the old-time operators, nor were they allowed at first to have much to say about refinery operations. Instead, experimental laboratories were built for them and they were told to produce results on a semi-commercial scale. History testifies how well these men did their work. The basic ideas underlying all of our present-day practices were conceived in that period and each individual process was worked out on a semi-commercial scale before a single plant unit was designed. Such developments brought to the attention of refinery managers the vital importance of technical control of refinery operations and paved the way for the era of expansion which followed the war years.

At the end of the war many refinery plants in this country were in poor physical condition and the equipment in service was not suited for the class of work that a modern refinery had to do. During the boom years following, new and modern construction was the order of the day. The executive heads of many of the old companies realizing this, were willing to give over the active running of the oil industry to younger men of the new school but still maintained such a connection that their valuable experience and direction were still available. New types of refining units

were coming on the scene, and these units were in the hands of the new generation. Engineers and chemists were at hand who had received all of their training under the new conditions. The combination of these forces has made possible the great strides in refinery technology which we have witnessed in the last ten years.

Just as the manufacture of lamp oil (prime white kerosene) had given impetus to the industry in the 19th century, the production of synthetic motor fuels furnished the inspiration in the 20th. This time, however, the industry found itself with greater resources both in men and equipment than had been the case in the earlier period. Technically trained men had gained experience in refinery practice from semi-commercial development work and were in position to build and operate complicated refinery units. The systems of operating on a laboratory scale where a close control of operations was maintained were bodily applied to the refinery when commercial units were put in operation. So much depended on positive control both from the standpoints of safety and yield that no refinery manager could be content with the old style methods of operating. Success in special fields such as pressure cracking drew attention to the desirability of placing all refinery operations under similar control. The result has been that no modern refinery can stay in the game unless every operation is watched by a competent technical staff. So far as actual contact with refinery operations goes, the technical staff functions as an auditor, whose units of measure are yields and quality instead of dollars and cents.

Modern Methods of Technological Control

Having traced in a general way the progress of technical operations in refineries from early times, we can now pass to the consideration of a full scale technical staff suitable for a modern refinery. The chief executive officer of a company expects from his technical staff information along four definite lines which may be expressed as follows: (1) He wishes to know whether or not his present equipment and methods of operating are yielding products of full quality and in the amounts actually present in his charging stocks; (2) whether the individual operations in his plant are being carried out in the quickest, cheapest and most efficient manner; (3) whether new processes, apparatus or products offered him by outsiders have real merit and should be investigated, and (4) it must be possible for him to have available the patent history of every process he is using or is being developed in his organization, as well as the same information for any piece of apparatus now in operation or which may be contemplated, or of any product which he is now producing or intends to produce.

In order that these four prime requisites may be taken care of, the technical staff may be divided into two main groups, one of which will

deal with all matters relating to actual or proposed refinery practice, and the other with the outside investigations and patent searches.

As a center for operations of the above-mentioned staff, a general laboratory should be provided equipped with all modern apparatus and having a personnel of competent oil inspectors and chemists. This group is charged with responsibility for the quality of all materials or products bought or sold by the company. Besides this routine work, men with special training should be available for detail work in any field in which the company may have an interest. The chief functions of this unit are to keep close watch on the quality of all raw and finished products in the refinery and to furnish analytical data on materials from all sources. Of almost equal importance is the manner of routine examination of competitive products and the recognition of all points of merit displayed by them.

Small Scale Workups for Controlling Current Refinery Operations

An essential factor in the scheme of technical control proposed above is the provision of an experimental plant. In it, small scale units designed to operate as nearly like refinery counterparts as possible are fitted up so that any desired operation met with in the refinery itself may be carried out but on a much smaller scale. Samples ranging from 1 to 50 gal. in quantity may be required for these operations. Such an experimental plant had best be housed in a separate building designed to reduce fire hazards to a minimum. To this experimental plant are sent all samples of crude and intermediate products from which yields of commercial finished products are desired. Various kinds of distillations, chemical treatment and filtration tests make up a large part of the work performed. The staff must consist of experienced stillmen and treaters who have had long contact with small scale work. They are charged specifically with determining potential yields of products from all actual or proposed refinery stocks. It is from these units that the basic data for the technical control of refinery operations are obtained.

The value of the class of work outlined in the above paragraph can best be illustrated by giving typical examples of method used in controlling certain major operations. As is well known, all producing companies in active fields maintain field scouts whose duty it is to collect samples of crude from every new pool discovered and forward them to the central laboratory. These samples are subjected to routine inspection for the purpose of classifying them and then they are worked up according to the refinery method which would be applied. Inspection reports on field crudes are prepared, types of which are shown below:

Typical Workups Covering Different Kinds of Crude Oils on Small Experimental Scale

A. Crude from Appalachian Fields

1. *Tests on Crude*

Gravity, ° Bé	41.2
Flash	RT
Pour	0
BS, per cent	0.2
Sulfur, per cent	0.12
Color	Amber

500 *C. C. Distillation*

	Deg. F.	Deg. Bé.
Over	154	
10 per cent	253	68.4
20 per cent	320	59.3
30 per cent	392	52.2
40 per cent	472	47.1
50 per cent	547	42.7

	Per Cent.
Per cent. at 221	5.4
284	14.9
392	30.0
420	31.5
440	34.0

2. *Tower Distillation of Crude*

Charge 100 Per Cent. Crude — Gravity 41.2° Bé.

Cut	Grade	Crude, Per Cent.	Gravity, Deg. Bé.
Over to 46.7	400 end distillate	35.0	59.1
Over to 45.4	420 end distillate	38.0	57.9
Over to 44.4	437 end distillate	41.0	56.8
Over to 43.4	450 end distillate	43.0	56.2
Bottoms	Reduced crude	55.6	32.2
Loss		1.4	
		100.0	

Tests on Products

Grade	400 End	420 End	437 End	450 End	Reduced Crude
Gravity	59.1	57.9	56.8	56.2	32.2
Over	124	126	127	130	500
10 per cent	184	166	191	194	
20 per cent	212	218	225	226	
30 per cent	234	241	250	252	
40 per cent	255	266	274	277	
50 per cent	276	287	298	307	
60 per cent	296	310	322	333	
70 per cent	315	336	353	360	
80 per cent	339	359	378	390	
90 per cent	364	386	406	419	
End	399	420	437	450	
Per cent. at 221	24.0	21.5	18.5	18.0	
Per cent. at 284	54.0	49.0	44.5	42.5	
Per cent. at 392		92.0	85.0	81.0	

The yields of kerosene, fuel oil, wax distillate and cylinder stock from this crude are so well known that further working of reduced crude is not necessary.

B. Crude from Mid-Continent Fields

1. *Tests on Crude*

Gravity, ° Bé	35.0
Flash	RT
BS, per cent	0.3
Sulfur, per cent	0.39
Color	Dark green

500 *C. C. Distillation*

	Deg. F.	Deg. Bé.
Over	136	
10 per cent	194	75.2
20 per cent	326	60.0
30 per cent	409	51.0
40 per cent	503	43.3
50 per cent	602	37.6
50 per cent. bottoms		23.2

2. *Towerstilling Crude*

Charge 100 Per Cent. Crude Gravity 35.0° Bé.

Cut	Grade	Crude, Per Cent.	Gravity, Deg. Bé.
Over to 43.7	400 end distillate	29.0	59.3
43.7 to 40.5	41° kerosene	12.0	41.7
Over to 41.9	91⁄392 goods	33.0	57.3
41.9 to 40.9	41° kerosene	5.0	41.6
Over to 41.0	450 end distillate	36.0	55.0
Bottoms	Reduced crude	62.5	26.0
Loss		1.5	
		100.0	

1. *Tests on Products*

Gasolines

Grade	400 End	91⁄392 Goods	450 End	7 Per Cent. Casinghead 93 Per Cent. 91⁄392 Goods
Gravity	59.3	57.3	55.0	58.8
Over	130	135	140	113
10 per cent	169	180	188	168
20 per cent	206	212	221	202
30 per cent	230	237	250	231
40 per cent	254	264	274	252
50 per cent	276	288	304	281
60 per cent	298	312	332	312
70 per cent	314	338	358	338
80 per cent	333	365	384	365
90 per cent	359	390	418	390
End	399	430	452	430
Per cent. at 221	26.0	23.0	20.0	27.0
Per cent. at 284	54.0	48.0	43.0	51.0
Per cent. at 392		91.0	83.0	91.0

Kerosenes

After Making	400 End	$^{91}/_{392}$ Goods
Gravity	41.7	41.6
Flash TCC	120	120
Viscosity	460	465
Initial	380	394
10 per cent	400	418
20 per cent	425	435
30 per cent	434	442
40 per cent	440	446
50 per cent	448	450
60 per cent	452	454
70 per cent	457	457
80 per cent	464	462
90 per cent	478	470
End	496	488

C. Gulf Coast Crude

1. *Tests on Crude*

Gravity, ° Bé	21.6
Flash	195
Fire	235
BS, per cent	0.2
Pour	0
Sulfur, per cent	0.35

2. *Distilling Crude*

Charge 100 Per Cent. Crude — Gravity 21.6° Bé.

Cut	Grade	Crude, Per Cent.	Gravity, Deg. Bé.
Over to 26	Gas oil	29.0	29.6
26 to off	Lub distillate	59.6	20.7
Bottoms	Flux	10.3	12.1
Loss		1.1	
		100.0	

3. *Rerunning Lub Distillate Over Lye*

Charge 59.6 Per Cent. Crude — Gravity 20.7° Bé.

Cut	Grade	Charge, Per Cent.	Crude, Per Cent.	Gravity, Deg. Bé.
Distillate	Lub stock	94.0	56.0	21.0
Bottoms	Caustic fuel	5.0	3.0	9.0
Loss		1.0	0.6	
		100.0	59.6	

In order to work up lub stock from Section 3, a predetermined ratio of production of different grades must be adopted. This is usually taken as average of plant production over a period of time. The breakup desired in this particular case is 1.7 parts 750 stock, 12.8 parts 500 stock, 17 parts 300 stock and 1.7 parts 200 stock. On the above basis the lub stock produced under Section 3 will show:

4. *Reducing Lub Stock for Test Bottoms*

1. *Reducing for* 750 *Stock*

Charge 56.0 Per Cent. Crude Gravity 21.0° Bé.

Cut	Grade	Charge, Per Cent.	Crude, Per Cent.	Gravity, Deg. Bé.
Distillate	Lub stock	45.0	25.2	23.4
Bottoms	750 stock	54.0	30.2	18.8
Loss		1.0	0.6	
		100.0	56.0	

One and seven-tenth per cent. of the crude was set aside as 750 stock and remainder of distillate and bottoms mixed for new charging stock.

2. *Reducing for* 500 *Stock*

Charge 53.7 Per Cent. Crude Gravity 21.1° Bé.

Cut	Grade	Charge, Per Cent.	Crude, Per Cent.	Gravity, Deg. Bé.
Distillate	Lub stock	35.0	18.79	24.2
Bottoms	500 stock	64.0	34.37	19.0
Loss		1.0	0.54	
		100.0	53.70	

Five hundred viscosity stock, equivalent to 12.8 per cent. of crude, was set aside for this grade and distillate mixed back with the residue.

3. *Reducing for* 300 *Viscosity Stock*

Charge 40.37 Per Cent. Crude Gravity 21.6° Bé.

Cut	Grade	Charge, Per Cent.	Crude, Per Cent.	Gravity, Deg. Bé.
Distillate	Lub stock	30.0	12.11	25.4
Bottoms	300 stock	69.0	27.86	20.2
Loss		1.0	0.40	
		100.0	40.37	

Three hundred viscosity stock, equivalent to 17.04 per cent. of crude, was held out and balance mixed with distillate fraction.

4. *Reducing for* 200 *Viscosity Stock*

Charge 22.93 Per Cent. Crude — Gravity 22.7° Bé.

Cut	Grade	Charge, Per Cent.	Crude, Per Cent.	Gravity, Deg. Bé.
Distillate	Lub stock	40.0	9.17	26.4
Bottoms	200 stock	59.0	13.53	20.5
Loss		1.0	0.23	
		100.0	22.93	

Two hundred viscosity stock, equivalent to 1.7 per cent. of crude, was set aside for this grade and balance mixed with distillate.

5. *Reducing for* 100 *Viscosity Stock*

Charge 21.0 Per Cent. Crude — Gravity 22.9° Bé.

Cut	Grade	Charge, Per Cent.	Crude, Per Cent.	Gravity, Deg. Bé.
Distillate	Gas oil	19.6	4.12	27.2
Bottoms	100 Vis. stock	79.4	16.67	21.4
Loss		1.0	0.21	
		100.0	21.00	

Tests on Products

Grade	750 Stock	500 Stock	300 Stock	200 Stock	100 Stock
Gravity	18.8	19.0	20.2	20.5	21.4
Flash	385	365	335	315	280
Fire	445	425	380	360	315
Viscosity at 100	768	522	314	213	110
Pour	5	0	0	0	0

Summary of Products

Grade	Crude, Per Cent.	Gravity, Deg. Bé.
Natural gas oil	29.00	29.6
Cracked gas oil	4.12	27.2
100 viscosity stock	16.67	21.4
200 viscosity stock	1.70	20.5
300 viscosity stock	17.04	20.2
500 viscosity stock	12.79	19.0
750 viscosity stock	1.70	18.8
Fuel	13.30	11.1
Losses	3.68	
	100.00	

With reports of the kind shown above refinery executives are able to keep fully informed on the quality of current new production and to pick, when possible, grades best suited for the plant. Over a period of years a file will be accumulated which includes type crude oils from all over the world and any new pool discovered can be placed with relation to all others.

Application of Close Control on Small Scale to Current Refinery Operations

Next in importance to obtaining a knowledge of the possible products that can be obtained from any given crude, such as described above, comes the control of daily routine operations in the refinery. The superintendent in charge of operations has daily reports made up showing the quality of all raw and finished stocks on hand. These must of necessity be qualitative in nature and serve only to protect against sudden changes in crude supply or faulty operations in individual units of the plant. If, however, a "bogey sample," amounting to at least a barrel, representing an aliquot portion of each day's stock, is made up to cover a month's operation, materials will be at hand for independent workups of the stocks into the products which the refinery is supposed to be making. For this purpose bogey samples are needed consisting of (1) average crude, (2) average rerun naphtha, and (3) average process still charging stock, in case there is a special process, such as a cracking process, in the refinery. At the same time, a copy of the refinery yield statement and a composite of tests on all products made must be provided.

A form is then made up on which average tests for all products made by the refinery are shown. Bogey workups are then outlined to produce the same quality stocks as were made in the refinery. The final report shows refinery and bogey yields in parallel columns. Detailed descriptions of the apparatus used in this work would be of little value for the reason that each refining unit has its own special designs of equipment, which would have to be matched in experimental sized units. The importance of bogey barrel runs can best be shown by a type case. Let us assume that we have a typical refinery equipped with tower stills for crude and rerun operations, coke stills operating on reduced crude and process still capacity to handle all available cracking stock. The materials charged to the various stills might show:

	Percentage Crude
Crude to stills	100.00
Cracking stock to stills	126.71
Pressure still tar to stills	1.47
Total to stills	228.18

Let us assume that the operations in the refinery required the production of five grades of gasoline and naphtha which might be produced in the following amounts:

	Percentage Crude
64–66 gasoline	1.62
60–62 gasoline	1.60
USM gasoline	47.28
437 end gasoline	9.91
450 end naphtha	8.35

The individual operations in the bogey workup should be reported as follows:

A. *Quality of Crude*

1. *Tests on Charging Crude*

Gravity, ° Bé	35.5
Flash	RT
Pour	20
BS, per cent	0.3
Sulfur, per cent	0.36

	Deg. F.	Deg. Bé.
Over	137	
10 per cent	247	72.0
20 per cent	316	59.6
30 per cent	385	51.4
40 per cent	469	44.6
50 per cent	555	38.8
50 per cent. bottoms		22.8

2. *Towerstilling Crude*

Charge 100 Per Cent. Crude — Gravity 35.5° Bé.

Cut	Grade	Crude, Per Cent.	Gravity, Deg. Bé.
Over to 43.1	400 end distillate	35.0	58.3
Over to 41.8	$^{91}\!/_{392}$ goods	38.0	57.0
Over to 40.3	437 end distillate	41.0	55.9
Over to 39.9	450 end distillate	43.0	54.9
Bottoms	Reduced crude	55.5	24.9
Loss		1.5	
		100.0	

1. *Tests on Products*

Grade	400 End	9⅓92 Goods	437 End	450 End	Bottoms
Gravity	58.3	57.0	55.9	54.9	24.9
Initial	123	124	124	126	
10 per cent	176	176	182	184	
20 per cent	208	209	216	218	
30 per cent	231	235	246	250	
40 per cent	252	257	266	274	
50 per cent	276	282	294	304	
60 per cent	294	312	321	332	
70 per cent	316	335	351	366	
80 per cent	340	358	362	392	
90E	368	390	414	451	
End	400	420	438		
Per cent. at 221	25.5	24.5	24.0	21.5	
Per cent. at 284	55.0	52.0	47.0	44.0	
Per cent. at 392		90.5	84.0	80.0	

The purpose of the above breakup is to provide accurate data on quality of crude being charged from month to month. It is, of course, apparent that no refinery could operate commercially and turn out a single grade of gasoline like any of those shown. Sales department demands are varied and many grades must be manufactured. Runs for grades of gasoline specified in the foregoing paragraph are made as follows.

1. *Towerstilling Crude*

Charge 100 Per Cent. Crude — Gravity 35.5° Bé.

Cut	Grade	Crude, Per Cent.	Gravity, Deg. Bé.
Over to 47.8	60–62 distillate	27.00	61.6
60–62 grade finished		1.60	61.6
		25.40	
47.8 to 42.2	Gasoline distillate	10.00	
USM gasoline finished		35.40	57.5
42.2 to 40.2	Water white distillate	7.00	41.2
Bottoms	Reduced crude	54.50	25.4
Loss		1.50	
		100.00	

Tests on Products

Grade	60-62 Grade		USM Grade		Water White Kerosene	
	Refinery	Bogey	Refinery	Bogey	Refinery	Bogey
Gravity	62.7	61.6	58.3	57.5	41.0	41.2
Initial	104	116	100	124	387	402
10 per cent	152	167	165	180	415	424
20 per cent	182	192	205	208	426	434
30 per cent	208	210	233	233	432	438
40 per cent	227	227	258	256	438	441
50 per cent	244	243	280	278	444	444
60 per cent	260	260	304	304	451	447
70 per cent	277	279	330	328	460	449
80 per cent	300	294	356	354	471	454
90 per cent	328	323	386	387	490	459
End	389	364	426	419	536	479
Per cent. at 221	37.0	36.5	25.5	25.5 fl.	148	90
Per cent. at 284	73.0	73.0	51.5	52.0 vis.	450	400
Per cent. at 392	97.0		91.5	91.0		

2. *Reduced Crude and Pressure Tar to Coke*

Charge 55.97 Per Cent. Crude Gravity 25.2° Bé.

Cut	Grade	Charge, Per Cent.	Crude, Per Cent.	Gravity, Deg. Bé.
Distillate	PS stock	94.35	52.78	31.8
Bottoms	Coke	5.2	2.91	
Loss		0.5	0.28	
		100.0	55.97	

3. *Skimming of Pressure Still Stock (Refinery Figures)*

Charge 132.36 Per Cent. Crude Gravity 31.0° Bé.

	Charge, Per Cent.	Crude, Per Cent.	Gravity Deg. Bé.
Heavy rerun naphtha	4.27	5.65	52.6
PS* charging stock	95.73	126.71	
	100.00	132.36	

* PS means pressure still; PT, pressure tar.

4. *Process Still Operation* (*Refinery Figures*)

	Charge, Per Cent.	Crude, Per Cent.
PS distillate	30.35	38.46
Gas oil	54.22	68.70
PS tar	1.16	1.47
PT flux	11.70	14.83
Loss	2.57	3.25
	100.00	126.71

5. *Naphtha Rerun*
Sources of Stock

	Crude, Per Cent.	Gravity, Deg. Bé.
Heavy naphtha	5.65	52.6
P S distillate	38.46	50.3
Total	44.11	50.4

Towerstilling Rerun Naphtha

Cut	Grade	Charge, Per Cent.	Crude, Per Cent.	Gravity, Deg. Bé.
Over to 49.4	64–66 gasoline	47.00	20.73	63.9
64–66 finished		3.67	1.62	63.9
		43.33	19.11	
49.4 to 41.1	Gasoline stock	20.00	8.82	
US motor made		63.33	27.93	
US motor finished		26.93	11.88	
		35.40	16.05	
41.1 to 40.8	Gasoline stock	2.00	0.88	
437 end made		37.40	16.93	
437 end finished		22.47	9.91	57.0
		15.93	7.02	
40.8 to 40.3	Gasoline stock	4.00	1.76	
450 end finished		19.93	8.78	54.0
Bottoms		25.50	11.25	35.0
Loss		1.50	0.67	
		100.00	44.11	

Tests on Products

Grade	64–66		US Motor		437 End		450 End	
	Refinery	Bogey	Refinery	Bogey	Refinery	Bogey	Refinery	Bogey
Gravity, ° Bé....	65.1	63.9	58.3	58.1	57.0	57.0	53.2	54.0
Initial...........	98	102	100	116	103	120	107	126
10 per cent......	144	154	165	176	172	178	183	192
20 per cent......	168	171	205	210	213	216	231	234
30 per cent......	200	199	233	236	243	246	269	268
40 per cent......	219	218	258	262	269	268	304	297
50 per cent......	236	235	280	282	293	288	333	322
60 per cent......	249	248	304	302	319	312	353	343
70 per cent......	264	262	330	319	343	330	383	363
80 per cent......	280	276	356	334	368	348	403	378
90 per cent......	309	290	386	357	399	366	420	391
End............	365	320	428	378	433	342	442	406
Per cent. at 221..	41.5	41.5	25.5	24.5	23.0	22.5	18.0	17.0
Per cent. at 284..	81.5	86.5	51.5	51.0	47.0	48.0	34.5	35.0
Per cent. at 392..			91.5		87.5		75.5	90.5

Summary of Products

Grade	Refinery		Bogey	
	Crude, Per Cent.	Gravity	Crude, Per Cent.	Gravity
64–66 gasoline distillate..............	1.62	65.1	1.62	63.9
60–62 gasoline distillate..............	1.60	62.7	1.60	61.6
USM gasoline distillate..............	47.28	58.3	47.28	57.7
437 end gasoline distillate............	9.91	57.0	9.91	57.0
450 end naphtha....................	8.35	53.2	8.78	54.0
Water white distillate................	3.24	41.0	7.00	41.2
Furnace oil.........................	7.20		None	
Flux..............................	11.47		14.83	
Miscellaneous......................	1.26		0.37	
Coke.............................	3.87		2.91	
Loss	4.20		5.70	
	100.00		100.00	

A careful examination of the type bogey barrel workup shown above reveals the fact that a number of points require explanation. It was assumed in this case that all crude and rerun naphtha in the refinery were handled in continuous tower stills where the degree of fractionation commercially obtainable could never equal that of a laboratory batch unit, tower equipped, performing the same type of operation. For this reason the refinery products always show a wider boiling point range

than the corresponding products from a laboratory batch still. This is seen quite plainly by studying the distillation tests throughout the workup. However, it so happens that when some intermediate point (percentage off at 221°, 284°, or 392° F.) is taken as the control, the yields of products can be matched to a fraction of a per cent. on the crude. Again, it must be borne in mind that refineries are obliged to produce certain intermediate products, such as furnace oil and the like, which contain potential motor fuel stocks. In judging the efficiency of refinery operations, low boiling point materials so diverted should be deducted from the bogey figures. In the type example, the furnace oil made contains enough light ends to account for the shortage of total gasoline production. The place where the refinery statement shows up short is, however, on the production of water white kerosene. This amounted in the above case to about 4 per cent. or more on the crude.

A superintendent who has bogey barrel workups on his crude each month is in a position to select the units in the plant where yield is falling below expectation and from experience is able to judge whether additional recovery will pay. In the type case presented for your consideration, it is quite likely that the loss in throughput capacity suffered in attempts to obtain full yields of water white stock would cost more than could be compensated for in the value of the small increased percentage yield involved.

The details given on workups of crude oils and bogey samples from the refinery all deal with a single operation, namely, distillation. This is by far the most important single operation in a plant, but there are many others of only slightly less consequence. The nature of these secondary operations is such that good results can only be obtained when tests are conducted on a semi-commercial scale. Certain other activities of a technical staff call for test work under like conditions, so it will be convenient to discuss these matters under a separate head.

Control of Refinery Problems Carried Out on Semi-commercial Scale

The type of work we are now to consider has to do with checkups on refinery operations where full scale commercial operations have to be met with. For this purpose, a plot of ground at some point convenient to all refinery services, such as electricity, steam, air, and so forth, must be enclosed and space allotted for tanks, lines, stills, pumps, agitators, filters, and other pieces of refinery equipment. In these should be placed units built on a scale to handle stocks in carload lots, if necessary—probably, on scales ranging from 20 up to 100 or 200 bbl. per day. In addition, ground must be set aside for the construction of new pieces of apparatus developed within the organization or offered to it by outside parties. The staff chosen to handle this unit must be selected with care

and the top man must have special talent for the work. He has to know by instinct how to handle any problem and be able to pick merits or flaws in any operation to which he is giving his attention. In fact, to be a genuine success he must eat, drink and breathe petroleum. The personnel of his force should be made up largely of young technically trained men who have the ability to grasp the essential points in problems and the determination to make a thing work or else to find out the reason why it will not. The best slogan such a group of men can have is "Because a thing failed the hundredth time is no proof it will not work on the 200th attempt."

The work carried on in this plant has to do with study of routine refinery operations having for its purpose to find out whether the products made are of the best quality and whether or not costs are being held at the lowest figures possible. The important points to consider are throughput, efficiency of reactions where reagents are employed, and the good or bad quality of the final end products. In addition to this, the matter of corrosion, the wearing out of parts of equipment, the frequency of replacement, and other practical problems, should be borne in mind. This method of operating has a great advantage over full scale work for the reason that all steps in a given process are directly under the eye of the man in charge. He is able to detect weak spots that would not be observed by the refinery staff in routine operations. In this way ideas for improvements or for entirely new processes are conceived.

When a change in an old process is proposed or an entirely new method for doing a certain piece of work suggested, experimental apparatus is at once built to incorporate the new practice and put it in routine service. Months and even years of study must be devoted to the new unit before results of a satisfactory nature can be produced. The apparatus may have to be changed a dozen times in this period to meet all refinery conditions. Having passed this stage, the apparatus is fitted up just like a normal refinery unit of the class to which it belongs. It is then operated on a scale having a throughput of 100 to 200 bbl. and all test data are secured based on regular refinery conditions. After a series of such runs in which costs, yields, and quality of products shade those for current operations, the proposition is in shape for commercial application.

When inventors with nothing more than paper patents offer propositions to the company, they may be asked to join the experimental staff for a period and work out their propositions at the company's expense, the understanding being that the inventors will share in the profits from any commercial use of their basic ideas. What usually happens is that the ideas, if good, are taken over by the company and developed by the experimental staff. In that case the inventor is generally satisfied with a modest royalty.

Another type of inventor may come to the company with his process all worked out. If the preliminary experiments give promise of real money value he will be asked to construct a semi-commercial unit at the experimental plant and instruct the regular force in its care and operation. It will be operated to produce the specific products which the refinery has to produce. In the vast majority of cases it will be found that the new process will not work on the stock supplied or else the costs are all out of proportion to the value of the products produced. Occasionally a good process is found and the chance that such a one will be overlooked makes it necessary to investigate them all.

The varied character of work done in such a plant calls for the exercise of a great deal of ingenuity in constructing apparatus. The idea is, to have one typical piece of each kind of apparatus, likely to be required, in such shape that it can be incorporated in any arrangement of apparatus or process being studied. The basic operations dealt with are distillation, chemical treating, dewaxing and filtration, most of which have to be performed in a continuous manner. The first object is always to produce marketable specification products. Ways often have to be devised for small scale testing of products at various intermediate stages in a process and from these have been developed many of the newer types of refinery processes. Among these groups of activities belong such operations as mechanical stirring operations of the oils in place of the old air blowing system, contact filtration of oils with fine earth as opposed to the old percolation of oil through porous earth, the dewaxing by centrifuge or filter aids as against the older methods of cold settling or pressing, the reactivations of decolorizing mediums in multihearth furnaces, such as are now widely used, instead of an internally fired rotary furnace, treatment of oils in the vapor phase with solid reagents in place of liquid phase treatment with lquid reagents. The details of methods and descriptions of apparatus used have no place in this paper for the reason they have no direct bearing on technical control.

Investigation of Outside Processes

Let us now turn our attention to the investigations of new processes brought to the attention of an oil company by an outside party or group. This is not to be confused with the investigation of new processes developed within the company itself and which was discussed earlier in the paper.

Processes, and by these I mean also apparatus, auxiliary equipment, or products which are brought to the notice of oil companies, range all the way from mere ideas, without even a definite plan in the mind of some inventor, to complete commercial propositions often fully developed and fully protected by patents. Such processes may cover most any

subject. A few of those which come regularly to the technical head of any oil company are processes for cracking oil, processes for producing or recovering sulfuric acid, manufacture of soaps and greases, vacuum distillation processes, new types of pumps, oil burners, or investigations of deposits of fuller's earth.

Usually, there are three persons to be considered in any new proposition. They are the inventor, his financier, who is also some times his promoter, and his lawyer. As a rule, the idea is first brought to the technical executive by letter or in the form of an interview. In the majority of cases, the new proposition is disposed of at this first contact, as most of them are not practical or of any value in the light of the experience of the man in charge of this department. By asking a few well chosen and pertinent questions, the whole matter is often ended as far as the oil company is concerned. If, however, the idea presented is of sufficient importance that the proposition must be investigated, then the technical man must be called in and probably arrangements are made for a demonstration of the process. If the new proposition is in the form of a product, samples may be sent to the central laboratory and there investigated. According to the degree of development of the idea and the scale on which it can be demonstrated, one man, or probably a technical man and several helpers, will be sent to the location of the plant or apparatus to be investigated and a preliminary opinion obtained as to the merits of the proposition.

In reporting an investigation of this nature, the report should be divided into two parts: First, a letter to the head of the technical department or to the person to whom the report is to be made, and second, the report proper covering the results of the preliminary investigation. The letter should be brief and should merely state name of the process, date of investigation, those present, with their connections, and the location of the plant where the investigation took place. Attached to the letter should be the report of the investigation. The report may well be divided into the seven following classes of information as regards the process: (1) Historical; (2) the process in its present development; (3) record of the demonstration made by the investigator; (4) commercial application of the process; (5) comparison with other known similar processes, (6) advantages and disadvantages of the process, and (7) the investigator's personal remarks on the process, and his reasons for recommending its adoption or rejection.

The following may serve as an amplified outline of a report of a cracking process. This outline really covers the questions, answers to which should be secured, so that the technical head will have as much information on which to base judgment as to whether or not the preliminary contact with the process should be followed up and a complete demonstration made:

Historical (1)

1. Who was the inventor, when did he first get his idea and how did he conceive it?

2. The inventor's present development of the process, where did he do his experiments and to what extent did he develop his ideas (laboratory or commercial scale)?

3. How did the inventor finance the development of his invention? Did the inventor form a company to develop or exploit the process? If so, give the name of the company, his present contract with it, the men interested, the location of the main office and in what state the company is incorporated? (Why.)

4. What has the company done to develop the process commercially? Who owns it now? Is the process patented? If so, who owns the patent? Is it in litigation? If so, with whom? Get the number of the patent and the number of patents and names of the patentees with whom there is litigation.

5. Will the company or inventor sell the process outright, or will they allow the use of the process on a royalty basis?

6. Who else has investigated the process? What did they think of it, and if possible, get a copy of their report.

7. Is the process being used by anyone else? If so, what royalty do they pay and what are the terms of their contract with the owners of the process?

The Process in Its Present Development (2)

1. Is the process as practiced at present in the laboratory, in semi-commercial or commercial state?

2. Give a description of the apparatus used, with blue print or photostat, if possible. Obtain also photographs and an operating flow sheet.

(*a*) Still shell, size, material, etc.
(*b*) Type of tubes, length, size and material.
(*c*) Mechanical agitator, if any—type, speed of agitation and type of drive.
(*d*) Size and type of pumps, steam boilers, etc.
(*e*) Vapor line and reflux towers.
(*f*) Type of condenser, whether under pressure or without.
(*g*) Casinghead plant, or absorbent towers for non-condensible gases.

3. General Operation.

(*a*) Whether a continuous or batch process.
(*b*) Stock charged, gravity, initial and other general tests.
(*c*) The capacity of the still, rate of charging per hour or minute, feed pump and control.
(*d*) Pressure used and how controlled.
(*e*) Preheaters and forewarmers.
(*f*) Fire box, type and construction and insulation.
(*g*) Circulation from bulk supply; type of artificial circulator.
(*h*) Recycling.
(*i*) Control of run and taking off vapors.
(*j*) Condenser and run down tanks.
(*k*) Total heating surface of still or tubes (gal. distillation per hr. per sq. ft. heating surface).
(*l*) Fuel used, whether gas, coal or oil, and quantity burned per hr. and per gal. distillate made.
(*m*) Any special features, such as catalysts, special methods of handling the carbon problem or any special feature of construction.

Record of Demonstration Run (3)

1. Condition under which run was made.

(*a*) Condition of the plant.

(*b*) Superintendent and helpers.

(*c*) Oil stock used with complete tests of same.

(*d*) Whether run was made continuously or batch?

(*e*) Length of run, whether in one period or in shifts?

(*f*) Data to be taken during the run.

(*g*) Personal checking up of quantities of raw material handled, capacity of tanks and feeding rates.

(*h*) Provide some method for checking up fuel consumption.

2. Log of run. Time, important data taken, readings of instrument and remarks or observations made.

3. Yields:

(*a*) Grade.

(*b*) Volume in gallons or barrels.

(*c*) Weight in pounds.

(*d*) Percentage by volume based on distillate.

(*e*) Percentage by volume based on original stock.

(In this run shall be included each finished product made, the amount of coke produced and the loss in fixed gases.)

4. Quality of products.

(*a*) Comparison with original stock (fractional distillations, physical and chemical tests and graphs).

(*b*) Do the products need rerunning or refining?

5. Rerunning of products from the still.

(*a*) Operation.

(*b*) Apparatus.

(*c*) Length of the log (duration of run in hours).

(*d*) Yield of products.

6. Refining of products.

(*a*) Method.

(*b*) Apparatus.

(*c*) Yields and losses in treating. Special problems.

7. Fuel efficiency.

(*a*) Total fuel burned.

(*b*) Pounds fuel consumed per gal. oil run through process, of distillate made, and lb. fuel per gal. gasoline made.

(*c*) Efficiency of fire box.

(*d*) Temperature of waste fuel gases (analysis of these gases if possible).

(*e*) Preheaters or forewarmers and gain in temperature from their use.

(*f*) Temperature of residual oil drawn off or circulating through exchangers.

8. Efficiency of process.

(*a*) Capacity of units—gal. of bbl.

(*b*) Rate of charging, gal. per hr.

(*c*) Barrels of distillate per sq. ft. heating surface.

(*d*) Average rate of distillation, rate percentage per hr. based on the charging capacity of the still.

9. Cost balance.

(*a*) Cost of raw material used per ton or per bbl. oil run.

(*b*) Value of products made.

(*c*) Cost of raw material charged to still or used up.

(*d*) Value of products made or of unused material left over.
(*e*) Value of fuel consumed.
(*f*) Labor cost.
(*g*) Total investment in the plant.
(*h*) Maintenance 10 per cent. of investment.
(*i*) Interest on investment.
(*j*) Allow for depreciation at proper rate.
(*k*) Cost of steam and electricity.
(*l*) Total cost of producing—gal. of gasoline.
(*m*) Total value of products made.
(*n*) Net profits per day or year.
(*o*) Barrels of gasoline per year per dollar invested.
(*p*) Profit per year per dollar invested.

Note: If there are several runs, tabulate parallel and average, for example:

	Run 1	Run 2	Run 3	Average
Item	——	——	——	——

Commercial Application of Process (4)

1. If on a laboratory scale how does inventor propose to operate the process commercially?
2. What is the largest size of units possible?
3. Will the plant be built in separate units or batteries?
4. Will it be operated as a continuous process or intermittently?
5. The total investment will be so much. You can charge so many bbl. per day and the yield will be so much of such and such a product.
6. Do the products need rerunning or refining in order to make them marketable?

Comparison with Similar Processes (5)

1. Chemical process.
2. Cracking process.
3. Treating process.

Note.—Compare the process with other known processes with respect to investment, size and yields, fuel, economy, yield of gasoline per heating surface, cost per gallon, labor operation, safety from fire and explosion, rate of distillation and quality of products.

Advantages and Disadvantages (6)

1. Large or small capacity of plants.
2. High or low yields.
3. Obsolescence.
4. Fuel economy.
5. Quality of products.
6. Safety.
7. Depreciation and maintenance.
8. Simplicity of construction and operation.
9. Amount of labor needed for operation.
10. Do you need special castings or equipment or can the plant be built from standard parts?
11. Elasticity of the process or range of oils that can be used as stock.
12. Range of products obtained.
13. Is the loss in fixed gases large or small, and what is the nature of these gases?
14. Is there a large loss in coke and does the formation of carbon place difficulties in the way of operation?

The first investigation of a process or contact with a new idea is practically an effort to obtain as much reliable information as possible regarding the proposition submitted. A consideration of this preliminary report then puts the technical head of an oil company in a position where he can decide whether or not the proposition is worthy of further consideration. In case this conclusion is reached, arrangements are usually made for a second demonstration. This should be on a semi-commercial scale or even commercial scale, if possible. Enough men should be sent under some head technical man familiar with this line of work to take over the proposition and operate it over a long period of time, with the company's own men operating on their own oil and keeping their own data. No run should be shorter than 24 hr. It is not necessary to go into details as to the method of conducting such a test. One would, of course, obtain not only the information furnished in the preliminary report but carry the figures far enough so that there will be complete yield, fuel, cost, and other figures available for final study.

The technical man should not, however, overlook one important fact in conducting such a test in another man's plant. He must take into consideration the fact that the average inventor or party developing a new process has not the varied experience, or, we might better say, the specialized experience in oil refining that he has, and usually one must bear in mind that with the facilities of his own company and their experience at his demand, considerable improvement could be made in the construction and operation of the plant, and probably more efficient heating means, condensing means, and auxiliary equipment could be employed. The investigator must always report the process as it actually is and the products as they are actually produced, but it is a good thing to also advise his chief as to the possibilities of the process and what one experienced in the oil industry could make out of it. As mentioned above, inventors often present processes to an oil company, but, due to circumstances, usually financial, they are not in a position to build any plant or to make a demonstration. In such a case, the ideas, if they look worthy of consideration, are developed on a sort of cooperative basis by the inventor and the oil company.

Prior Art Searches

As mentioned several times earlier in this paper, one of the most important phases of technical control in the oil industry and one that is becoming every day more and more important is the subject of prior art searches. These searches must be conducted almost continuously for either one of two purposes. First, the prior art should be searched thoroughly to see what patent protection, if any, can be given new ideas which are conceived in the research, process development department, operating,

or any other part of the organization. These ideas may be along the line of a new process, may cover some new piece of equipment or apparatus, or may be a new product or composition. Second, it is always advisable to know from a study of the prior art if one is within his rights in operating a regular refinery process, or whether he is liable to litigation for infringing somebody's patented process. The oil industry has moved in cycles and has seen many changes in the manner of operating and in just what at any particular time is considered the important product. This has led to the rather complicated patent situation at present. It is not within the scope of this paper to discuss this particular phase of the subject further.

Due to the difference in purposes of the two above-mentioned kinds of prior art searches, the technique of carrying out the search is a little different in each case. When one is studying the prior art, it is best to make the search as systematic as possible and to keep the results of the search in a definitely classified manner so that they are readily available to patent attorneys or such others as may have to study or refer to them later. In making what is known as a prior art search to see what protection can be given a new idea, the entire field of that particular idea must be searched, but in making the second class of search, where one simply wishes to see whether or not the processes which he is already operating are old art, the search is usually made to find instances in the prior art which anticipate certain definite ways of operating a process or constructing a piece of apparatus in which one wishes to carry out a process. The writers have found the following a very convenient system for conducting a prior art search and for reporting it in a classified, readily available manner.

The search proper may be divided into two main parts: Part 1, covering material searched or studied, and part 2, containing references found pertinent to the subject on which prior art is desired.

It is well to divide the material searched into sections, such as the following: Section *A*, books; section *B*, periodicals; section *C*, patents; section *D*, miscellaneous publications such as dissertations, bulletins, brochures, and such as are not books or regular publications; section *E*, reports, affidavits, and other unpublished matter.

In each one of these sections, the material searched can be entered and given numbers so that they can be referred to later, and also for the purpose of cross entries which are made in the second part of the search under "References Found." In other words, each book, periodical or patent studied will have a symbol and this can be used for identification in the actual references found.

It is very essential in a search of this nature that any literature source studied be entered in its proper section, giving enough detail on the reference that it can be readily located again, in case those receiving the

results of the search wish to study the original reference. In the case of a general search on a given subject for the purpose of obtaining protection for an idea, it is often sufficient merely to make an abstract of the literature reference and enter it under the proper section of material searched, giving it its proper item number under that section, but in case a search of the second class on specific points is conducted, it is better to use the two part search idea, the first part being the sections of material searched and the second part a list of the classes under which the references found are divided. In this case the abstract prepared from a study of the original reference and which is entered under the proper section of material searched contains at the end a list of class references, in case there are any, together with the item number in that class. The purpose of classification is that where a pertinent reference is found it can be entered and elaborated under the proper class so that, at the end of a search, one studying the subject on which the search was made can find all the references pertaining to any particular angle of the subject abstracted and listed in one place, with each item containing a cross reference back to the original source from which the information was obtained.

Searches of the nature outlined above should be carried out by some technical man familiar with the standard processes carried on in oil refineries and with research work in the oil industry. After he has completed his search, the results should be turned over to regular patent attorneys as they can best judge of the legal aspects of the matter.

One advantage of carrying out a search along the lines described above is that the search is accumulative and new items of material searched and references found can be incorporated at will. If the search is extensive and covers the literature both of the English and foreign language and all of the patents as well, it may become quite a volume, in which case it is advisable to prepare an author index. Each entry should be given the search symbol under material searched so that the reference can be immediately found if desired.

Conclusions

In considering the operations of the technical staff for a modern unit in the petroleum industry, we have covered a field that requires the annual outlay of a large sum of money. The natural question here is: "Does this expenditure justify itself?" The returns from such an investment appear in two forms, one tangible and the other intangible. Bogey barrel workups induce both. Routine operators in any kind of a plant are content with current yields as long as stocks do not cause trouble in the specific operations with which they are concerned. A stillman wants throughput; a treater, freedom from trouble at the agitators and a wax plant man, good pressable distillate. When no laboratory control whatever is maintained over operations, each process yield is considered

satisfactory in comparison with previous operations. If, however, operators know that control breakups of stocks for full potential yields are to be made on the exact materials they handle each month, the natural tendency will be to watch details of operation, quality of products and yields closely to avoid censure from the superintendent. The value here is intangible, but nevertheless, it represents thousands of dollars per year in reduced refinery costs and in ultimate earnings.

In another direction, bogey barrel workups have a substantial value. A superintendent cannot demand greater yields per barrel of crude run from his operators unless he can lay before them positive evidence that that crude actually contains those added quantities. When breakups are made on specific stocks charged to stills and results are set up against refinery yield statements, defects in commercial operations are discovered. This kindles the interest of the foremen on the job and spurs them on to get the highest yield and quality possible from the materials they handle. In many cases, yields lost in primary operation can be recovered in secondary ones, but this means a waste of a certain amount of fuel and a loss in still capacity, both of which considerations run up the over-all operating costs. The ideal operation is to separate all the desirable products in continuous one-pass operations and the nearest approach possible to this ideal is the prime object of bogey barrel control. Practically complete separation of test distillates in one-pass operations as against poor fractionation and secondary cleanup may mean as much as 5 c. per bbl. of crude run in savings. There can be no question but that such a saving justifies all the expense involved. Bogey barrel runs supply the means for finding out where improvements in yields can be expected and serve as a checkup after better operating conditions have been established.

Passing to the semi-commercial operation with actual or proposed plant processes, this class of work reveals the shortcomings of current equipment and points the way to improvements. Here, individual steps can be followed in minute detail and the degree of refining obtained, closely watched. In many cases, the causes for the failure of end products to meet exacting specifications can be located and the plant equipment modified with a modest outlay of capital. Much more valuable results in this field come from the conception of entirely new ideas for processes or products. These usually originate in efforts to solve some troublesome current problem. All such matters serve as the basis for patent applications and, in this way, the company is able to build up a reserve of useful practices of potential value, some of which might acquire great worth. This is particularly true at this time when the industry is faced with great quantities of very refractory crude oils. The vigorous following of all suggestions in this field, keeps the staff engaged with problems months or even years ahead of current operating requirements and provides

experimental data upon which commercial plants can be constructed. The cost for this service is only a small fraction of the real value possible in the ultimate results.

One hardly needs to point out the importance of having first hand information on all new processes, apparatus and products offered to the company. The purpose for which an inventor designed a process may not be of immediate interest to the company, but no one can predict when changing conditions might create a demand for it. Unless all promising ideas are followed up systematically and their relations to current or anticipated problems fully known, the company will not be in a position to estimate their possible values and, therefore, will be handicapped in negotiating for the purchase or use of those considered important. Not to be overlooked in this field are the personal contacts company representatives are able to maintain with leaders in kindred lines of business. These contacts throw into relief the prevailing trends in the industry and focus the attention on probable future changes in practice or products. Money spent for this class of work usually does not pay a direct return, but its indirect value is very high.

The patent search division of the activities of a technical staff is virtually a new development and few organizations have pushed this angle of the question to the limit of its possibilities. The potential value of this class of work has been set forth in that section of the paper devoted to this subject. Its primary value, of course, lies in the protection afforded the company against unwarranted infringement suits. Notices of infringement will be voluntarily withdrawn in many instances when opposing patent attorneys can be shown the prior art applicable to the particular case at issue. An organization having such information in shape for immediate use has an insurance policy of value all out of proportion to its low cost. Prior art searches also furnish the company with substantial backing in all patent matters it may wish to press on its own account. With such a fund of information to draw upon, patent attorneys can inform themselves on the vital points in any proceeding and advise when patent protection is worth obtaining.

At our present, highly developed stage of refinery practice, it is only natural that many companies should have overlapping patent protection in certain fields and it is of first importance that each should know exactly where it stands in relation to all the others. Attempts to negotiate agreements for the exchange of rights in such a case cannot be carried out with complete success from the viewpoint of any single company unless that company knows the prior art and has the patent history of all matters involved. When settlements for patent infringements such as are frequently awarded by courts are set up against the total cost to a company of its patent search work, it will be seen that no investment of company funds can pay greater real dividends.

The proper management of the huge resources entrusted to executives in the oil industry today calls for the exercise of sound judgment on many diversified activities. The successful administration of such a responsible position rests principally upon the possession of accurate information along the three following lines, knowing (1) as far in advance as is humanly possible what the market will be demanding in quality and quantity of petroleum products, (2) what kinds of crude oils are and will be available, (3) what kind of processes will be needed to produce them at a profit. The organizations that maintain full technical staffs for control of all refinery operations will have the information they need and will be able to hold their places in the front line of the industry. Those that do not, however, will not remain long in the running. The activities of a complete technical staff touch every vital interest of the company and furnish the standards against which the efficiency of all operations are measured. The cost of the service rendered by such a staff is returned over and over again in lower production costs and higher quality of commercial products. To refinery people who have not given serious thought to technical control of refinery operations, our parting word is to apply at once as much as your resources will permit and set aside for expansion a reasonable portion of the gains its practice brings to you.

DISCUSSION

H. G. Smith,* Port Arthur, Tex.—In reviewing the literature on the early history of the industry, including early patents, I am struck by the apparent fact that refining processes, yields and types of marketable products have really in most cases followed rather than anticipated the economic or industrial needs of the times. When another interesting petroleum product had been developed it was usually advisable to proceed with the development of a demand. For example, take the case of lubricating oils of the lower viscosities; as soon as the users of fatty oils found out that petroleum oils could be substituted, wholly or partly, for these, the petroleum refiners were able to find a market outlet for this large proportion of the crude. Perhaps more development work has been carried out toward the enlargement of the potential market than on refining processes.

Some of the early investigators appear to have mastered the fundamentals of present-day refining practice, but in many cases were too far ahead of the times to have benefited thereby. If a process or patent has been developed too far ahead of the actual need or demand for the product involved, it has no direct practical value to the refiner who is endeavoring to exist by the proceeds of sale of demanded refined petroleum products, but it may have real value from a future or protective standpoint.

I do not consider that the dark ages in petroleum refining technique ended during the period 1910 to 1918, at least not for the entire industry, nor that the basic ideas underlying all our present-day practices were conceived during that period, although obviously many present-day men then absorbed basic ideas underlying current practices. Developments by different refiners have been at different paces. It is possible that some have been too rapid, as I consider some of the equipment of recent design so overdesigned that high upkeep and operating costs may be involved.

* Gulf Refining Co.

Mention is made of a lack of cordiality in the reception of the younger technically trained men by many of the older men of the industry. Is not this a trait of human nature? The experienced men have oftentimes been confronted with the task of teaching the younger the fundamentals, so as to provide a sound foundation upon which improvements could be built. However, such a situation often works for the best in a rapidly growing industry; it stimulates thought.

As the development of knowledge as to refining practices is peculiarly a problem for each individual, the most successful man often being the one who avoids making the same mistake twice, there is, and has been, a very large amount of repetition of effort, much of it avoidable.

I have known of executive officers who expected information from a technical staff of somewhat wider scope than as outlined. However, the four definite lines appear quite acceptable. It is somewhat difficult for me to discuss the matter of the organization of the technical staff of a refiner. I am inclined to believe that the ideal one for each must be built up to suit the unique conditions involved.

Oftentimes, I think, too much work is required of a laboratory staff, sometimes directed toward the demonstration of the obvious, as indicated by past reports and experience.

One big problem of the petroleum technologist today is that of simplifying plant control, without sacrifice of plant efficiency or quality, so as to enable him to keep the number of men employed on routine laboratory work within reasonable limits. As the number of laboratory tests involved with satisfactory plant control increases markedly with increase in the number of crude oils processed and finished grades produced, the problem is one requiring constant study and vigilance.

With this problem in mind, I am inclined to believe that the amount of work outlined by Mr. Phillips and Mr. Miller for plant control, and some of the laboratory procedure, would involve too great a load for a very large plant.

It is my policy to employ more direct and simple routine tests, involving less manipulative effort; and to employ, whenever possible, factors based on operating experience and earlier experimental work in estimating expected plant performance, plant yields from a given crude, and the like.

For example, much can be done along this line from the results of the ordinary Engler distillation test, provided one's conversion factors are reliable, particularly in the matter of expected yields of gasoline and kerosene. As end point for gasoline fractions is no longer a real criterion of yields or quality of gasoline for many refiners, it is often not really necessary to repeat proof as to the feasibility of making a gasoline cut of a desired end point from a given stock by actually preparing a finished gasoline of that end point in preliminary laboratory work.

Perhaps one of the greatest difficulties involved in an attempt to simplify laboratory practice lies in the convincing of others that one's factors and results are reliable and acceptable.

Although the problem of simplifying practice is certainly an individual one, it is, or should be, one of interest to each refiner.

In amplification of my remarks: I do not wish to convey the impression that my policy is to curtail *all* laboratory work; rather to reduce all routine testing that is not considered necessary as a help in maintaining plant efficiency. The thought is that laboratory work, beyond certain limits, may better be expended on experimental or development work.

T. G. Delbridge,* Philadelphia, Pa.—It would be very helpful if Mr. Miller could give us some idea, broadly at least, as to how the cost of this technical control

* Supervisor, Process Division, Atlantic Refining Co.

is distributed between his four items and how the total compares with general refinery expense.

E. W. Isom,* New York, N. Y.—The Sinclair Refining Co., whose operations were the basis of this paper, has some eight refineries scattered over the country. We have quite a variety of equipment in these plants—at least we had at the start. We are getting fairly standardized now.

The monthly checkup as to what a refinery produced from its crude as against what could be gotten by a laboratory using the same methods as were available in the refinery, and with due regard to the products required of that refinery, was very helpful in bringing superintendents up to full efficiency. Many companies having several plants use the practice of matching the yields of one plant against another. Under such a system, any superintendent can produce plenty of alibis as to why he did not do as well as the other fellow, and we are still left in the dark as to where any particular plant fell down; and even the plant making the best showing for the month might still not be up to the highest efficiency. Our bogey barrel system of control enables us to know what any plant should have done during any period, and also to point out to the superintendent particular places in his operation requiring increased efficiency. I think this bogey barrel work, handled for eight refineries, costs the company the time of four men and maybe $25,000 worth of laboratory equipment. It is a very minor cost on our whole operation.

A subject Mr. Miller touched on only briefly was the standardization on qualities. We found it was desirable to check up each refinery at least once each month. All products made by one refinery are also made by two or three other refineries of the company. By having them each send in their samples, average samples of these products produced, we not only get a check on the quality, but also get a check on the instruments. That sort of work was invaluable in stopping customers' complaints and maintaining the reputation of the company.

T. G. Delbridge.—What do you consider a reasonable amount to spend for technical control?

E. W. Isom.—I would say that a company could easily spend on this class of work, which would tend to keep up the quality of the product, keep up full efficiency and point out the necessity of betterments, at least one cent a barrel on its throughput.

A. G. Peterkin, Jr.,† Philadelphia, Pa.—The method of controlling refinery operations and of attempting to maintain in that way maximum efficiencies with reference to yields has one disadvantage which it shares with most cost systems—it is a post-mortem method. By the time the results of the examination of the "bogey" samples are in the hands of the operators the damage has been done and the money lost over a considerable period of time. Here again might not the industry copy with benefit the procedure of other industries? If the intermediate as well as the finished products are examined when produced by standard methods and made to meet predetermined specifications, a great deal has been done to insure maximum yields, and the minimum of rerunning. Deviations from a specification are known promptly and the avoidable ones are remedied before much damage has been done.

A. E. Miller.—This bogey workup, of course, is different for each crude running for each plant, as Mr. Isom pointed out. But, by applying to the bogey sample operations exactly parallel to plant operations on that particular crude, the bogey sample, made up by taking small samples every day over a whole period

* Sinclair Refining Co.

† Development Engineer, Atlantic Refining Co.

of a month, is almost exactly like the crude run and gives reliable information on yield and can give information on quality if desirable. That is one of the chief advantages.

L. B. Smith.*—May I ask whether any effort has been made to control the fuel consumption in refinery operation and if so what steps have been taken?

E. W. Isom.—For many years we have been doing everything we can to cut down the fuel consumption, which is the largest single item of cost in the operation. That is done by having departments metered as to steam and each battery of stills measured as to fuel consumed and figures worked up at the end of the month to actual pounds of coal or barrels of oil used per barrel of oil handled. By this coal monthly checkup, and by putting special combustion engineers on the places where the firemen need the training, there has been a material reduction in the fuel used and steam consumed. Of course, most refineries have the men—at least we have them in our big plants on every shift—whose job is to watch for all steam leaks, which also cuts down the expense.

* Chemical Engineer, Atlantic Refining Co.

Chapter XII. Refinery Products and Problems

Sources of Automotive Fuels

By Frank A. Howard,* and Robert T. Haslam,* New York, N. Y.

(New York Meeting, February, 1928)

In a broad sense automotive fuel is simply fuel in general and includes coal, coke, wood, charcoal and gas, in addition to the full range of liquid combustibles. All of these are actually used, or have been used, commercially to some extent as fuel for automotive vehicles. The steam lorry burning coal and coke is a common sight on the roads of England. The fact that these coal-fired steam lorries have a distinct advantage in taxes over the conventional gasoline-driven lorry probably explains the survival of this vehicle. The omnibus, or charabanc, operated by city gas carried in a balloon container on the roof, was also at one time a common sight in England, although not as common as the ubiquitous steam lorry. These gas-operated vehicles have, however, disappeared from the streets in recent years, and probably owed their existence entirely to war conditions.

In France one of the largest motor vehicle manufacturers had last year more than 30 trucks equipped with regular gasoline engines in service in the Parisian area operating on producer gas obtained from a small gas producer mounted on the running board of the truck. Both wood and charcoal have been used in these gas producers. The authors were interested enough in this unique commercial development to spend some time examining the apparatus used and inquiring into the success which it had met. The picture is by no means an impossible one purely from the standpoint of practicability, but there is no doubt of the soundness of the conclusion that this is not a development which has any present important significance.

Powdered carbonaceous matter, coal, coke or lignite, has been used experimentally in special forms of internal combustion engines, but so far as is known, these have never been applied to automotive practice.

Range of Liquid Combustibles

In the field of liquid combustibles the full range has been exploited to some extent. Heavy residual fuel oils from petroleum have been

* Standard Oil Development Co.

handled both with preliminary vaporization or even gasification, and injected cold in engines specially designed for this service. The intermediate distillate oils of the grade of kerosene and gas oil are in continuous use here and there under special conditions, both in direct injection engines and in carbureting engines. There has even been in South Africa and perhaps elsewhere some experimental use of cheap vegetable oils, and in Europe there are reports, not known to be reliable, of the experimental use of fish oil. In the United States the Hvid engine, which is capable of direct application at least for tractor automotive work, has been run as a stunt on butter fat and on animal oils.

Ethyl alcohol has had rather extensive use as a fuel for regular carbureting type automotive engines in various corners of the world, and a persistent attempt was made in the United States some years ago to exploit this fuel in admixture with gasoline and benzol. Methyl and isopropyl alcohols have been used, at least experimentally.

The archives of the patent offices of the world disclose proposed automotive fuels specifying singly or in combinations, a wide range of synthetic organic combustible liquids, and some of these, such as ethyl ether, are recognized blending agents for special service. Ethyl ether and ethyl alcohol are a combination which has received much attention; the principal function of the ether here being to compensate for the low vapor pressure of the alcohol, which renders starting difficult. Pure cyclohexane has been used as a reference fuel for high compression engine investigation and tetrahydronaphthalene occupied the headline space in the German technical press for a long period some years ago, being held out as a promising substitute for gasoline.

Electricity

It must, therefore, be recognized that automotive transportation has been shown to be capable of utilizing practically every common fuel, either through the intermediary of the steam boiler or directly in the internal combustion engine. It must not be overlooked that the storage battery-driven electric motor vehicle, which at one time was a serious contender, remains in the picture as a dependable, commercial, self-supporting competitor of the gasoline-driven vehicle in certain classes of service. Through the electric route the door to automotive fuel opens wide to admit even the power of the waterfall.

The principal value of this survey of the broad field of automotive fuels is to bring home the truth which the whole engineering world accepts in its sober moments but forgets at regular intervals, that the automotive fuel question is not a question of the feasibility of manufacturing a certain type of fuel at a low cost or even the feasibility of using this fuel in a practical manner in some type of automotive vehicle.

The Carbureting Engine—Its Role in Automotive Transportation

There is only one type of automotive vehicle which is known to be capable of providing automotive transportation of the kind which has built up this industry to its present status, *i. e.*, the vehicle propelled by a reciprocating internal combustion engine of the carbureting type. By a carbureting engine we mean one in which the charge at the time of ignition consists of carbureted air. A fuel which is incapable of use in such an engine is not an automotive fuel from any present practical standpoint. It is possible to go one step further and say that, as of the present day, the fuel must be sufficiently volatile to permit the carburation process to be carried out by substantially instantaneous vaporization in air at moderate temperatures.

Cost of Automotive Power

The cost of automotive power is made up of three main items: (1) original cost of the engine; (2) maintenance and depreciation charges on the engine; (3) cost of fuel. The sphere of usefulness of automotive transportation is fixed by the total cost of the motive power, not by the cost of fuel alone. This explains why gasoline is, statistically speaking, the sole automotive fuel, while kerosene, a cheaper product of equally great potentialities from the supply standpoint, of higher heat value, and even of fair volatility, is of no economic significance whatever at the present time. The best engines yet devised to handle kerosene as automotive power units are either lacking in essential elements of convenience or performance, or if modified to overcome these difficulties, are too heavy, too complex, and too high in fixed and maintenance charges to compete with the existing standard combination of gasoline fuel in a gasoline engine.

Sources of Automotive Fuel

We are at length, therefore, arrived at the real starting point for an analysis of the sources of automotive fuel. While all combustible liquids capable of use in carbureting engines are thoroughly practical automotive fuels, gasoline, or its equivalent, is the only one which will suit the existing type of engine. Only the combination of gasoline and a gasoline engine now gives a final net cost for the kind of motive power which is demanded by the public, at a figure low enough to support the industry. In arriving at this limiting cost figure, it is literally true that within wide limits the per gallon price of the fuel is relatively unimportant. In considering this last statement it should be remembered that transportation and marketing costs, which are almost independent of the base price of gasoline, amount in the aggregate to something of the order of 10 c. per gallon. It is believed to be true that gasoline or its equivalent must remain practically the sole source of automotive fuel, up to a base

price level at least three times and perhaps four to five times its present base price. For example, the average base price of gasoline in the United States at the present time is in the neighborhood of 7½ c. per gallon at the refinery. A base price level of 22 c. would in itself probably make little change in the fundamental situation.

To the extent that this premise is correct, the conclusion must be that gasoline, or its equivalent will constitute the only source of supply for automotive fuels until the automotive world is able to produce a generally satisfactory power unit of characteristics differing from those which have now been accepted as standard for nearly 30 years. We therefore accept the terms gasoline and motor fuel as synonymous for present practical purposes.

The primary sources of gasoline are (1) crude petroleum, (2) shale, (3) coal, via hydrogenation. The supplementary sources are (1) natural gas, (2) coal, via distillation or gasification, (3) carbohydrates.

The sources listed as primary sources are each known to be capable of meeting the demand. The sources listed as supplementary are so classified because this seems to be their true economic function and present limit of possibilities, both from a quantitative and qualitative standpoint.

The present general status with regard to each of these sources is as follows:

Crude Petroleum

Crude petroleum is now produced in greater quantities than at any time in the past, and in fact in excess of current demand. Substantial quantities of crude oil production are shut in. Known crude oil reserves are greater in the aggregate than ever before. Geophysical methods of exploration now supplement surface geology and core drilling studies for the location of territory promising for the drill. The whole technique of oil production is improving. Foreign sources of supply are showing increasing ability to relieve the United States of the burden of supplying the world's requirements, which it has carried in times past with relatively little assistance. The American Petroleum Institute has officially endorsed, through resolution of its directors, development of the domestic heating market for petroleum, thus implicitly declaring its faith in the ability of the oil industry to carry any increased burden which this expansion may throw upon it, without endangering motor fuel supplies. The technique of cracking operations by which heavier fractions of petroleum oil are converted into gasoline continues to improve slowly but steadily with resultant lower conversion costs and better yields. As the one real source of automotive fuel, the position of crude petroleum in the world at large was never so nearly unassailable, from a cost and supply standpoint, as at the present time. At the same time there is now a keener realization than ever before of the true economic value of

petroleum and of the necessity for exercising good sense in the exploitation of the known reserves. Abundance of supply in sight is not accepted as a justification for wasteful production methods or uneconomic use.

Shale

The technical possibilities of shale as a source of automotive fuel remain substantially in the status to which they were advanced some 5 or 6 years ago following a period of higher prices in the petroleum market. Reserves of oil-bearing shale, in the United States especially, are determined with a reasonable degree of accuracy and are known to be far in excess of any present foreseeable requirement, even assuming that shale were compelled to carry the whole load of supplying the automotive market. However, the costs and difficulties attendant upon the mining and distillation of shale and in the refining of the crude product, coupled with the fact that shale reserves are in local competition with low cost petroleum supplies, prevent any active efforts to develop these sources of supply commercially. The amount of technical investigation which shale oil production is now receiving is probably less than at any time in the last 10 years.

Coal

On the other hand, coal as a source of supply of automotive fuel has forged to the front very rapidly during the last three years. A great coal hydrogenation plant has been completed at Merseburg, Germany, by the I. G. Farbenindustrie A. G., and is now well started on commercial operations. The coal used is a low grade lignite or brown coal, which is produced locally by the most modern labor saving strip-mining methods. The motor fuel produced is of good marketable quality, not readily distinguishable from gasoline derived from crude petroleum. Those of us who have had the privilege of visiting this wonderful industrial development at Leunewerke leave with the feeling that the applied sciences of chemistry and engineering can face the future with calm assurance in the conviction that the world will never want for automotive fuel at a reasonable price so long as coal is available. Through hydrogenation the coal reserves of the world are now also its oil reserves, not directly quantitatively but nearly enough so that the general statement is true for the purpose of this discussion.

Synthetic Fuels

About coincident in time with the commercial development of the coal hydrogenation methods in Germany there has been a scientific and limited commercial development along two other lines, *i. e.*, the synthesis of a complex organic combustible liquid known as synthol from water gas by Dr. Franz Fischer (so far only an experimental achievement), and

a direct and simple synthesis of methanol from the same raw material by the I. G. Farbenindustrie A. G. which is commercial. By these two methods, both of which require preliminary gasification, coal becomes a supplementary source of motor fuel.

The direct extraction of light hydrocarbons ranging from propane to hexane from natural gas accounts for something like 11 per cent. of the present motor fuel supply of the United States. Both qualitatively and quantitatively this is a desirable supplement to gasoline derived directly from crude petroleum. Its qualitative supplementary value is somewhat affected by the increased use of cracking processes, which may be viewed as a sort of man-made duplication of nature's processes.

High and Low-temperature Coal Distillation

The coal distillation art divides itself naturally into two branches, the present commercial high-temperature distillation which yields metallurgical coke, gas, and a small fraction, perhaps 1 to 2 gal. per ton of light oils useful for motor fuel purposes, and low-temperature distillation processes, yielding so-called smokeless fuel intended for general consumption as a substitute for natural coal and up to 15 gal. per ton of combustible liquids of distinctly poor quality as compared with crude petroleum.

The high-temperature distillation process is of course represented by the conventional by-product coke oven and through its induction of benzol, has an established permanent place, although a minute one, in the motor fuel picture. The low-temperature distillation art suffers from a severe handicap at every step. No commercial development of apparatus or process seems to be quite satisfactory or even satisfactory enough to invite capital in any large amounts for further development. The character of the oil product has been referred to. The public reaction to the solid product which must remain the principal product of the process is not accurately known. For these reasons any conservative estimate of the low-temperature distillation art necessarily places this in the list of supplementary rather than primary sources of motor fuel.

Alcohol as a Supplementary Fuel

The production of ethyl alcohol by fermentation is an established supplementary source of supply of motor fuel. At one time a very large proportion of the motor fuel sold in Havana, Cuba, consisted of a mixture of 90 per cent. ethyl alcohol and 10 per cent. gasoline. In Central America, in the Philippines and Hawaii and some other isolated spots ethyl alcohol is reported to have been sold commercially as a motor fuel, admixed with gasoline or ether, or with both. The French national carburant, as defined by law, consists of a mixture of gasoline and dehydrated ethyl alcohol, dehydration being necessarily resorted to in order that the mixture might be made with a sufficient proportion of gasoline

present to give even reasonably satisfactory performance in existing engines. The effort to secure any really commercial distribution of this fuel has been abandoned however.

Substantially all of the alcohol which has gone into the motor fuel markets on a commercial basis has been that obtained from the fermentation of cane molasses, at times and at places where the latter had no other market. Inverted starch, the regular distillers' mash, has supplied a small amount of alcohol to the motor fuel trade. Proposals for the production of alcohol from cellulose and miscellaneous vegetable products have been experimentally demonstrated but have never amounted to a commercial business as far as is known.

Conclusions

The general conclusion from this brief survey of a field which has unlimited technical possibilities both from the engineering and chemical side is the following:

Gasoline or its equivalent must be considered synonymous with automotive fuel for the present day and for the foreseeable future. Crude petroleum, shale and coal exist in the requisite quantities to provide singly or in combination an indefinitely large supply for the future. With the conclusion of the year last past the third of these primary sources has become definitely established as a practical source for a satisfactory product, at a reasonable cost. Supplementary sources in the order of their importance are natural gas, by-products from coal distillation and fermentation.

This summary ignores established technical possibilities, and even some important commercial but small achievements, such as methanol synthesis, but it is believed to be a reasonably complete engineering review of the picture.

DISCUSSION

R. E. Wilson,* Whiting, Ind.—What is the anti-knock value of the fuel made by the Bergius process?

R. T. Haslam.—To all intents and purposes, it is equivalent to or better than straight run gasoline.

G. Egloff,† Chicago, Ill.—While you were abroad, did you see any automobiles operating on gas derived from gas plants?

R. T. Haslam.—No, I did not. I believe that all the trucks and buses in London that were using gas have been taken off the streets on account of the low price of gasoline. That was distinctly a wartime measure.

---

* Standard Oil Co. (Indiana).

† Director of Research, Universal Oil Products Co.

T. G. Delbridge,* Philadelphia, Pa.—Mr. Haslam, with hydrogen available as cheaply as the I. G. can produce it at Merseburg and with no protective tariff, could the Bergius motor fuel compete with gasoline?

R. T. Haslam.—Without in any way trying to be facetious, I would like to ask Mr. Delbridge the same question.

G. Egloff.—I would like to ask the approximate cost per gallon.

R. T. Haslam.—The I. G. is producing gasoline from coal and selling it through the Gasoline A. G., of which they are part owner. Obviously, the cost would depend upon local conditions, the size of the plant, etc. It is my own belief that the cost would not be so great as to eliminate coal as a supplementary source for the supply of gasoline and that gasoline so produced could be used widely without causing undue economic disturbance through its high price. In other words, the gasoline from this source would fit into our present-day economic structure without upsetting the automotive industry. I do not mean to imply that the cost would meet that of present-day gasoline.

* Supervisor, Process Division, Atlantic Refining Co.

Research, the Stabilizer of the Petroleum Industry

By H. W. Camp,* Tulsa, Okla.

(New York Meeting, February, 1928)

Research is defined, scientifically, as a "systematic investigation of some phenomenon, and also a search for hidden treasures." Chemists tell us that the hidden treasures of petroleum are far richer than the products which have been best known to us. However, these secrets will be discovered only through intensive and systematic, as well as scientific, industrial research. Indeed, the scope of the subject is so great that such an intensive research program should be assumed by a centralized organization supported by the petroleum industry as a whole. Such organization should assume the responsibilities for investigation of new products and development of markets for such products.

Gasoline, the chief product of the petroleum industry has become a cheap commodity. The continual uncontrolled overproduction of crude petroleum, the intensive competitive condition in the marketing of petroleum products and the increase of refining efficiency and installing of cracking facilities, have all combined to lower the market value of gasoline. The purchaser has profited from the lower cost of gasoline by way of lower prices so that today the most important product can scarcely be manufactured at a profit.

In other fields, manufacturing industries have diversified their products when faced by a similar situation. Thus, they have been able to widen their marketing outlook. Why cannot the petroleum industry employ the same tactics?

Right now we are hearing much discussion concerning the development of a wider market for existing petroleum products and new products for existing or prospective markets. For instance, we can cite recent developments for use of propane, butane and ethylene. Butane has been found to be an efficient and inexpensive refrigerant, especially adapted to home refrigerating systems. Propane and butane fractions of natural gasoline may be shipped under pressure and may be used as a substitute for acetylene in cutting torches in connection with oxygen. There is a possibility of substituting butane for gas oil in the carburation of coal gas, as we know that butane contains practically the gas enrichment as the same volume of gas oil and should prove to be a superior product for

* General Superintendent, Empire Oil & Refining Co.

this function. Ethylene, a hydrocarbon present in cracked gases, is finding an outlet for the artificial ripening of green fruits.

Following is a table of the more general uses of petroleum products as now established.

Uses of Petroleum

Hydrocarbon Gases

1. Fuel
2. Natural Gasoline
   a. Blending with refining gasoline
   b. Motor fuel
   c. Aviation fuel
3. Carbon Black
   a. Paint
   b. Ink
   c. Rubber tires
4. Liquefied Gases
   a. Coal gas enrichment
   b. Refrigeration
   c. Chemical synthesis

Light Distillates

1. Gasolines
   a. Motor fuels
   b. General solvents (commercial solvents)
2. Naphthas
   a. Dry cleaning
   b. Paints
   c. Soap manufacture
3. Kerosene
   a. Tractor fuel
   b. Heating
   c. Illumination

Intermediate Distillates

1. Gas Oil
   a. Diesel fuel
   b. Cracking stock
   c. Coal gas enrichment
2. Absorption Oil
   a. Gasoline recovery
   b. Benzol recovery

Heavy Distillates

1. Lubricating Oils
   a. Internal combustion engines
   b. Industrial uses

2. Technical Oils
   a. Flotation
   b. Medicinal
   c. Emulsifying
3. Waxes
   a. Candles
   b. Waterproofing
   c. Sealing

Residual Oils

1. Cylinder Stocks
   a. Bright stocks
   b. Steam cylinder oils
   c. Grease compounding
2. Fuel Oil
   a. Boiler fuel
   b. Furnace
   c. Gas manufacture
3. Greases
   a. Heavy lubrication
4. Asphalt
   a. Paving
   b. Roofing
   c. Paints
5. Coke
   a. Fuel
   b. Carbon products
   c. Graphite

Sludge Products

1. Acids
   a. Source of valuable chemicals

Petroleum, with its higher hydrogen content and mobile character, is an ideal raw material for the manufacture of synthetic organic compounds, which can be produced economically, the extent of which cannot even be predicted. However, we do know that many valuable organic compounds, now chemical curiosities, will be available in quantity as by-products of petroleum.

Organic Compounds Capable of Synthesis from Petroleum

Alkyl Chlorides.—Methyl chloride, ethyl chloride, carbon tetrachloride, chloroform and others. Chiefly used as refrigerants, solvents, anesthetics, and as a base for further chemical synthesis.

Alcohols.—Methyl, ethyl, propyl, butyl, amyl, higher alcohols and other alcohols such as the glycols. Chiefly used as general solvents and for the rayon silk and pyroxylin lacquer industries.

Aldehydes.—Formaldehyde, acetaldehyde, etc. Chiefly used in manufacture of synthetic resins (bakelite), antiseptics, denaturants and as a base for synthesis.

Esters.—Propyl acetate, amyl acetate, butyl acetate. Chiefly used as a base for pyroxylin lacquers and chemical synthesis.

Fatty Acids.—Formic, etc. Undeveloped at present time but edible fats, butter and lard substitutes, and soaps are possible from petroleum synthesis.

Ketones.—Acetone, methyethyl ketone, etc. Chiefly used for solvents and as a base for chemical synthesis.

Aromatics.—Benzol, toluol, etc. Dyestuffs, saccharin, explosives, antiseptics, perfumes, artificial leather, etc., can be synthesized from petroleum in competition with coal tar industry.

Synthetic Petroleum Chemicals Industry in Its Infancy

The synthetic chemical industry based on petroleum as a raw material is now in its infancy. However, this field has possibilities of equaling or even surpassing the industry built up around coal tar both in magnitude and variety of products. The vast majority of the petroleum derivatives are nonbenzenoid hydrocarbons and as such would not compete with coal tar derivatives. The present production of synthetic organic chemicals, especially the alcohols, glycols, aldehydes and their derivatives, is now being consumed by industrial markets, particularly in the lacquer, bakelite, automobile and explosive industries. Their uses are definitely established and the demand in these fields is increasing daily.

At the present time there is an annual consumption of approximately $900,000,000 worth of chemicals, a large part of which are organic chemicals capable of synthesis from petroleum. The extent to which synthetic petroleum products can break into that market depends upon the ability of the petroleum industry to manufacture a product of superior quality or better the prices of the same quality product as produced by present (other) processes. For example, the manufacturer of synthetic isopropyl alcohol must make a purer alcohol or must meet the price of isopropyl alcohol derived from acetone, a fermentation product. In case the manufacturer of the synthetic product can lower the price of isopropyl alcohol and still show a profit, the isopropyl alcohol derived from acetone will no longer be a factor in the market.

There are many other markets which will furnish large outlets for petroleum derivatives when they become available in quantity. The nature and extent of these markets are purely speculative in the light of our present knowledge. Many of them would probably have to be developed as the synthetic chemical industry expanded. They would have the advantage, however, of being relatively free from competition.

Cooperative Research in Gasoline and Gas Industries

The hidden treasures of petroleum, the extent and richness of which I have attempted to sketch (outline) for you, can be uncovered by research. If we survey other major industries such as cement, gas, electric, leather and steel, we find that they maintain cooperative research organizations. These research laboratories have developed new products, introduced untold economies, led the way to scientific marketing, and have saved millions of dollars for their respective industries.

In the past two or three years the petroleum industry has watched with interest the progress of the research program instituted by the Natural Gasoline Association of America. This program is supported by funds assessed from the members of the Association and the information so obtained is imparted to all of its members. Much credit should be given to this Association for its courage and foresight in pioneering a cooperative research program of this nature. The American Gas Association has been maintaining a similar program for the natural gas industry.

Benefits of a Centralized Research Program

The step that the natural gas and natural gasoline branches have taken in establishing cooperative research programs for the development of new products and the enlargement of present markets is applicable to the entire petroleum industry. A centralized research program supported by the petroleum industry as a whole would economize on funds and personnel, minimize duplication of work, coordinate discoveries, and the benefits accruing from such a program would be greater than any results obtained by independent research on the part of the various divisions of the industry. The different branches of the petroleum industry are interdependent and the general prosperity of one is conditional upon the prosperity of the others. Due to this interdependency, the scope of the problem and the fact that the petroleum industry is dealing with essentially the same class of chemical material, it is vital that the entire industry unite in a cooperative research program.

The oil industry is faced with the necessity of immediately developing new outlets for its products. However, our store of fundamental data concerning the chemical and physical properties of the compounds which constitute petroleum is relatively meager. Hence it would seem that the centralized research program should be divided into two lines of endeavor: (1) The immediate development of the more obvious possibilities for the wider utilization of petroleum products; (2) extensive research into the basic chemical and physical properties of the hydrocarbon series composing petroleum. The data gathered here would be the basis for further expansion in the development of synthetic petroleum products.

Synthetic Petroleum Products a Few Years Hence

Let us draw for your imagination, a picture of an average American Home a few years from now when petroleum synthesis has been developed so as to produce the various products which are within the bounds of possibility. The house is furnished of course with bakelite furniture which is extremely popular and is painted and decorated with pyroxylin lacquer. The heating system is operated with residual gas and furnace oil distillate burner, and refrigeration is effected by the use of methyl chloride. The linoleum, shingles, leather upholstering, bathroom fixtures, are all products of petroleum.

In the medicine chest we find camphor, turpentine, disinfectant, alcohol, vaseline, ointments and salves, purgatives, liniments and other items derived from petroleum. Milady laves her hands with soap, perfumes her bath and person with delicate perfumes, puts on her makeup, dresses in artificial silk and the unromantic and evil-smelling crude oil has through the ingenuity of man, furnished all these necessary aids to feminity.

A typical breakfast might consist of eggs cooked in lard substitute, toast spread with synthetic dairy butter and coffee sweetened with petroleum-derived saccharin.

Milady drives the car out to do her shopping, the car operating on knockless motor fuel, entirely different from our present fuel, and riding on tires developed from petroleum. The lacquer on the car, the leather upholstering, floor covering, instrument board, horn button and other fixtures are petroleum derived. Detouring a few blocks where workmen are blasting with explosives, originally petroleum, she stops and buys a package of her favorite hydrocarbon chewing gum.

These are a few of the vast number of possibilities in the application of petroleum and its allied gases. No doubt the field has only been scratched and organized and exhaustive research will surely develop many other products now unknown to anyone.

In subscribing to a program for petroleum research it must be borne in mind that Rome was not built in a day and in investing in a cooperative enterprise of this nature, we cannot reasonably expect to immediately revolutionize the petroleum industry. We could, however, expect to find that the dividends from this investment would be cumulative and would compound with the passage of time. The day may arrive when gasoline will be only a by-product of petroleum when considered from the point of view of net profit.

DISCUSSION

B. T. Brooks,* New York, N. Y.—I am fully in accord with Mr. Camp's suggestion that diversity of products would be helpful to the industry, or rather to a few

* Consulting Chemist.

units of the industry, but when one considers the tonnage or volume of gasoline, fuel oil, gas oil or the major refinery products, and then considers the quantity of the various organic products which can reasonably be imagined as some day being manufactured from petroleum, the number of such organic products which could conceivably consume any great proportion of any of the major refinery products is very small indeed. Twelve billion gallons of gasoline is a lot of gasoline. We have heard a good deal about synthetic methanol, yet the total domestic consumption of methanol was only about 8,000,000 gal. in 1927. Isopropyl alcohol is one of the few products which have been made by chemical processes from petroleum. Yet the cracking still gases from two or three refineries furnished enough propylene, part of which was converted into isopropyl alcohol, to more than saturate the market. These instances illustrate the general rule that minor products or specialty products may be lucrative if their manufacture is monopolized or limited to a very few manufacturers, but their effect on the industry at large, or upon petroleum as a raw material, is practically insignificant. The point is not that synthetic organic chemical manufacture is unimportant so much as that the petroleum industry is so great.

There is another aspect of the matter which, I am sure, all who have engaged in research will subscribe to. It is a matter of record that the greatest industrial innovations have grown out of researches of a very fundamental and highly scientific character. Whitney, Mees and Reese have emphasized this fact. The magnitude or importance of a discovery generally seems to vary directly with its remoteness from the obvious. Yet the amount of such scientific work which should be done in the field of nonbenzenoid hydrocarbons is enormous, and in general terms the gap between our fundamental chemistry of the hydrocarbons and their utilization for the industrial synthesis of commercial products is so great that it is at least doubtful if private corporations or petroleum refineries are justified in doing *this* kind of research.

The present development in the manufacture of solvent alcohols from petroleum which seems certain to grow to much greater proportions, is an excellent illustration of the general sequence of events which we may expect to see in other instances of the chemical utilization of petroleum. The fundamental chemistry involved in the conversion of the simple olefins, such as occur in cracking still gases and cracked gasoline, into alcohols by means of sulfuric acid, and the conversion of alkyl halides or chlorinated gasoline fractions into useful solvents, was investigated and published years ago. The refiner of today seeking specialty products may find his opportunity in working out the large scale manufacturing difficulties and even going deeply into the fundamental chemistry of chemical processes which our known organic chemistry shows may be possible, with petroleum as a raw material.

This is not to take a pessimistic view of the possibilities at all, but the organic chemist must take into account, so far as he may, the urgent technical problems of an enormous, live industry. Several years ago I reported what I believed to be a profitable chemical synthesis to the general manager of a large refining company. After a thorough discussion of the matter, he gave his decision in about the following words: "The process is all right. We shall do it some day, but just now we are too busy picking huckleberries. The explanation of that phrase is that when I was a boy I used to pick real huckleberries but I never picked all the berries in any one locality or bush but picked as fast as I could where the berries were thickest." I could not sympathize very much with that point of view, but a better knowledge of the industry compels me to agree with it. Two years ago Walter Miller estimated that the saving to the industry by improved distillation methods prevailing only a very few years ago, amounted to about $140,000,000 per year. Personally, I believe Mr. Miller's estimate was very conservative. In the last few years vast sums have also been saved by simplifying refinery operations, reducing vapor losses in the refinery and in oil storage, reducing treating losses by closed continuous systems and eliminating or reducing the

amount of sulfuric acid used in refining, improving the recovery of wax and lubricating oils, increasing the recovery of gasoline from natural gas, decreasing the losses occasioned by emulsions both of crude and in refining operations, decreasing the amount of coke formed in cracking operations, etc. The total dollar value of all these technical advances, largely passed on to the public, is certainly in excess of the total value of all the products of the American chemical industry, which is given in *Chemical and Metallurgical Engineering* for January, 1928, from U. S. Census figures, as $613,323,000.

In other words, I believe the technologists of the petroleum industry have obviously been solving their problems in the relative order of their importance. Chemical syntheses will come in due course. Some of the forward looking refining companies are giving it earnest consideration. It is earnestly to be hoped that researches in the wide field of nonbenzenoid hydrocarbons will be extensively carried out, to provide a great mass of scientific information out of which many things of industrial importance will be developed. This is where the emphasis on research should be put. The aid to such research afforded by the gifts of John D. Rockefeller and the Universal Oil Products Co. is the best indication that this situation is widely appreciated.

G. Egloff,* Chicago, Ill.—I believe that the oil industry should set aside millions of dollars for fundamental research, not alone along the lines suggested by Mr. Camp but along the lines which other thinkers could add.

Consider synthetic rubber and the possibilities of petroleum. Large sums are now being expended by outside organizations in an endeavor to produce material from petroleum which can be utilized for rubber synthesis. Synthetic rubber alone would certainly run into millions of dollars a year as income to the oil industry when successfully worked out. I have not the slightest doubt with enough men put on the job, that scientists will certainly solve that problem within our lifetime.

H. W. Camp.—Dr. Brooks speaks of the synthetic organic chemistry industry as being insignificant in connection with the total over-all picture of our refining industry. It is true probably that it is small but I firmly believe that in the years to come it cannot fail to be a factor in the diversification of petroleum products similar to other industries. I have in mind principally the extensive research which the DuPont company is carrying on to take care of its situation, with which we are all familiar.

Possibly I have not made myself clear to Dr. Brooks, in that I did not mean so much that the individual companies would carry on this research as that the industry as a whole would do so. If he will refer to my paper, it reads as follows: "a centralized research program supported by the industry as a whole would economize on funds and personnel, minimizing the duplication of work, coordinate discoveries, and the benefits accruing from such a program would be greater than any results obtained by independent research on the part of the various divisions of the industry." I do not feel that the private corporations of the refining division would be justified in doing this kind of research work but a centralized research program would certainly assist materially in bringing to light discoveries that would be of benefit to the whole industry.

Dr. Brooks points out that the petroleum industry is too busy picking huckleberries. Those of us in the refining industry know that the picking has been mighty slim for the last eight years and the majority of us have found few huckleberries, which is the chief reason for turning to research. The fields of chemical synthesis from petroleum are not wide open for the casual interloper to walk into and pick huckleberries when he cares to. The huckleberries of petroleum synthesis will only be uncovered by careful, intensive and extensive cultivation—research.

* Director of Research, Universal Oil Products Co.

The point I have been trying to make in this paper is that unless we do concentrate our efforts in the way that other industries are doing, such as the fruit growers, the cement industry, the steel industry and others, we are not going to be able to make the savings that we have in past years in the refining industry. I quite agree that there has been a tremendous saving from various efficiencies in the last few years and they have been passed on to the public but at the present time, the petroleum industry, as I see it from a refining angle, does not have these efficiencies to pass on any more and it is necessary for us to find some other means to offset the decreased price of gasoline in some other part of a barrel of crude.

Underlying Principles of Contact Filtration

By L. L. Davis,* Ponca City, Okla.

(New York Meeting, February, 1928)

The rapid increase in the use of pulverulent adsorptive materials in the so-called "contact filtration" process for decolorizing lubricating oils makes it desirable to consider some of the basic principles involved. The commercial methods and types of equipment now used are fairly well known, having been extensively described in the trade journals. In spite of this very little has been published concerning the factors which must be considered in the selection of a process or of a decolorizing material.

It is commonly understood that contact filtration more or less closely follows the laws of adsorption. These principles have been thoroughly described by Gurwitsch.[1] The contacting of neutral mineral oils seems to be adsorptive in character and apparently follows Freundlich's law of adsorption which may be expressed by the formula: $\frac{X}{M} = AC^P$

X = Color material adsorbed by the clay.
M = Amount of clay used.
C = Concentration of color material after equilibrium.
A and P = Constants for a given oil and clay.

Fig. 1 shows the decolorization curve for a natural, dark colored cylinder stock when contacted with various quantities of clay, curve R being made with natural Riverside Texas fuller's earth and T being made with an acid-treated clay from Texas.

As the Tag-Robinson color is inversely proportional to the depth of color, the reciprocal of these colors can be assumed to be a function of the concentration of coloring matter. The values of $\frac{X}{M}$ and C can, therefore, be calculated by using the reciprocal Tag-Robinson colors, and when these

---

* Assistant General Superintendent, Marland Refining Co.

[1] L. Gurwitsch: Scientific Principles of Petroleum Technology (1926) 397. (Trans.) D. Van Nostrand Co., New York.

values are plotted on logarithmic paper a straight line curve results. This is known as Freundlich's adsorption isotherm. Fig. 2 gives such

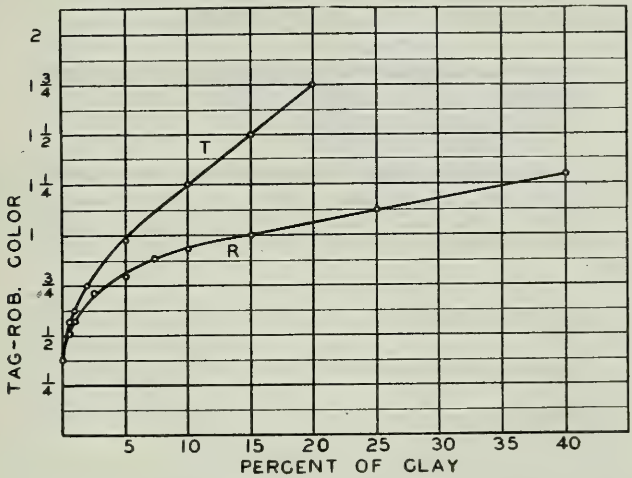


FIG. 1.—DECOLORIZATION CURVE FOR NEUTRAL, DARK COLORED CYLINDER STOCK WHEN CONTACTED WITH VARIOUS QUANTITIES OF CLAY.

Curve *R*, when made with natural Riverside Texas fuller's earth; *T*, when made with acid-treated clay from Texas.

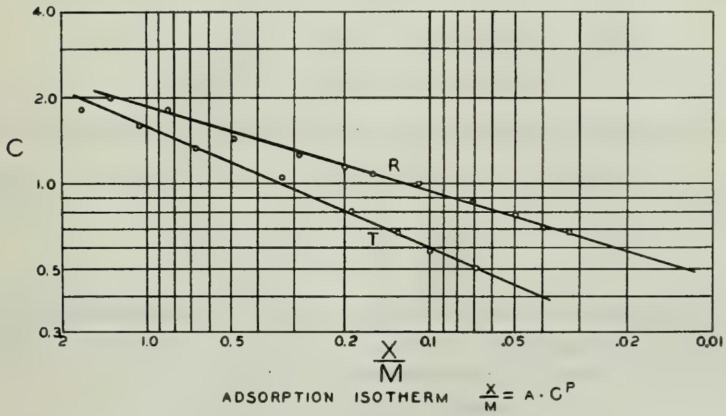


FIG. 2.—ADSORPTION ISOTHERMS FOR TWO CLAYS IN FIG. 1.

isotherms for the two examples given above. From these curves the constants *A* and *P* can be determined, giving the following adsorption

formulas for the two clays in question, when used on the dark cylinder stock:

$$\text{Riverside fuller's earth } \frac{X}{M} = 0.126,\ C\ 3.32.$$

$$\text{Acid-treated Texas clay } \frac{X}{M} = 0.342,\ C\ 2.30.$$

X = Color decrease—Tag-Robinson reciprocals.
C = Final color in Tag-Robinson reciprocals.
M = Per Cent. clay used.

A study of Freundlich's equation shows that if two clays have different exponents P, or, in other words, if the adsorption isotherms have different slopes, the relative efficiencies of the two clays will be different for each finished color.

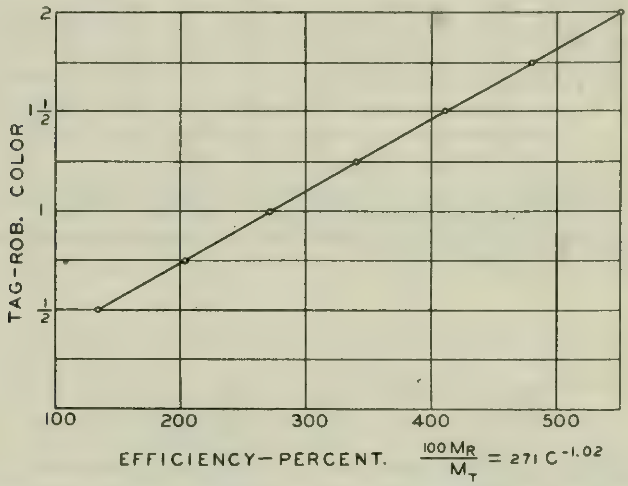


FIG. 3.—COMPARATIVE EFFICIENCY OF TWO CLAYS (SEE FIGS. 1 AND 2) FOR OIL USED.

This can be derived mathematically from Freundlich's equation to give:

$$\frac{M}{M'} = \frac{A'}{A} C(P' - P)$$

Substituting the values for A and P found above and multiplying by 100 to obtain the efficiency in terms of percentage of Riverside clay, this formula for the two clays in question becomes:

$$\frac{100M_R}{M_T} = 271C - 1.02$$

This formula (Fig. 3) shows the comparative efficiency of the two clays for the oil used. It will be seen that the relative efficiency of the acid-treated clay when used to decolorize neutral cylinder stock increases rapidly with the lighter finished colors.

These considerations show the absurdity of the usual practice of evaluating clays by reporting one in percentage of the other. Such a comparison is fallacious and has frequently led to misunderstandings between marketers of decolorizing clays and prospective customers. It

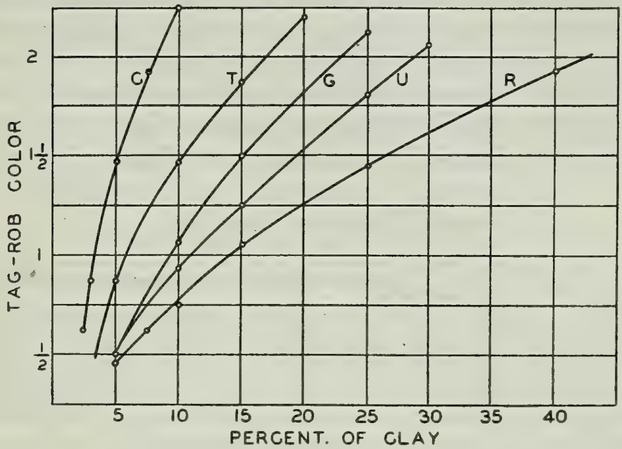


FIG. 4.—DECOLORIZATION CURVES FOR FIVE BLEACHING MATERIALS WHEN CONTACTED, WITH ACID-TREATED CYLINDER STOCK CARRYING 0.3 PER CENT. ACID SLUDGE. (For description of clays see text.)

should be remembered that the efficiencies will vary as greatly between different ways as between different colors, so that the exact conditions of any comparison must be fully understood.

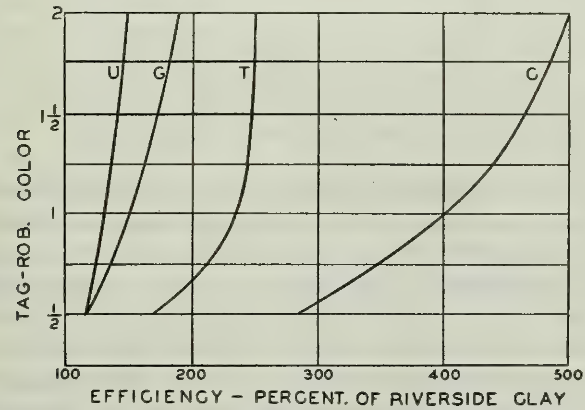


FIG. 5.—RELATIVE EFFICIENCIES OF VARIOUS CLAYS.

In the case of contacting treated oils in the acid stage, either for neutralizing, or neutralizing and decolorizing, the relationship is not so clear. However, decolorization appears to follow adsorption after the neutralization is completed and the variation in comparative efficiencies of clays

for different colors holds true. No mathematical relationship has yet been developed, but the efficiency curves may be determined with a fair degree of accuracy directly from the decolorization curves by determining the ratio of weights of different clays used to obtain the same finished color.

Fig. 4 shows the decolorization curves for five different bleaching materials when contacted with an acid-treated cylinder stock from Tonkawa crude, carrying 0.3 per cent. acid sludge.

C—Treated California clay in pulp form.
T—Treated Texas clay in pulp form.
G—Treated German clay in dry form.
U—Natural Utah clay.
R—Natural Riverside Texas clay.

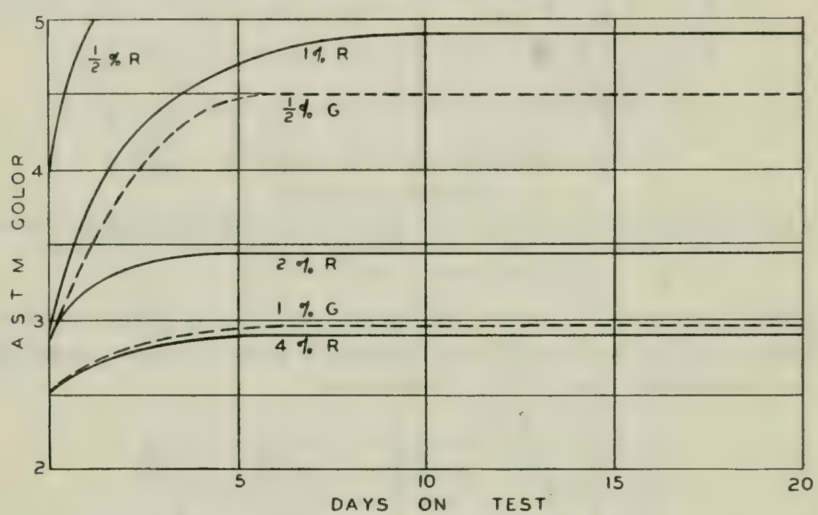


FIG. 6.—COLOR EFFICIENCY TESTS FOR 180 PALE OIL CONTACTED WITH RIVERSIDE FULLER'S EARTH AND WITH GERMAN TREATED CLAY.

It should be noted that neutralization was accomplished with approximately the same quantities of clay and with nearly the same resulting color. With the lighter colors, however, the quantity of the different clays used varies widely. From these curves the relative efficiencies of the various clays for each color have been determined and plotted in Fig. 5. This clearly shows the change in efficiency with the color desired. Thus, if it is intended to neutralize the oil only, the cheapest clay, *i. e.* Riverside, would be far more economical, whereas, if a 2-color is desired the use of the most expensive clay, that is *C*, would be possible.

STABILITY OF OIL

In addition to the actual neutralizing or decolorizing efficiency of various clays, their relative stabilizing effect must be considered. This

is particularly true in the case of pale oils. Fig. 6 shows various color stability tests for 20 days for 180 pale oil contacted with Riverside fuller's earth and with the German treated clay. The problem was to determine the relative value of the German clay to produce a stable 3 A. S. T. M. color. It will be seen that 0.5 per cent. of the German or 1 per cent. of Riverside clay, gave an initial color lighter than 3 A. S. T. M., indicating an efficiency for the German clay of 200 per cent. However, both oils darkened rapidly. It was then found that 1 per cent. of German or 4 per cent. of Riverside clay was required to give a color, which would not darken beyond 3 A. S. T. M. in 20 days, making the actual value of the German clay 400 per cent. of Riverside.

Revivification of Fine Clays

At the meeting in 1927, Walter Miller stated: "The lack of any practical method of recovering the finely ground fuller's earth for re-use, necessitating the discarding of the earth after one using, is quite an expensive procedure. This is not offset by the somewhat cheaper price of the average fine clay used for 'dry' contact bleaching and is accentuated in the case of the very expensive acid-treated types. Incidentally, the increasing use of the multiple muffle hearth furnace for burning and regenerating the coarse fuller's earth is materially decreasing the cost of percolation filtering."

The problem of revivifying fine earth is being studied intensively by many organizations. Two principal methods of attack are being followed, first, by burning the carbonaceous matter from the clay and second, by the use of solvents.

The majority of the highly efficient clays, such as the acid-treated pulps, lose their decolorizing ability if burned, so that this method is limited to fuller's earth and such dry acid-treated materials as are largely silica.

Fig. 7 shows the effect on the efficiency of fresh Riverside fuller's earth when heated to various temperatures between 100° and 1200° F. Curve *A* shows the color obtained with 15 per cent. of the dried clay on acid cylinder stock, while curve *B* shows the relative efficiency calculated to the same original weights before burning. It will be seen that there is a rapid break in efficiency above 300° F., and that at 1200° F. the clay is only 50 per cent. efficient.

Actual tests on burning used clay which had been thoroughly washed with gasoline show that a temperature of 1100° F. must be used if the carbonaceous material is completely removed. Burns in an electric muffle furnace give efficiencies of about 60 per cent., while tests in an experimental multiple hearth furnace gave efficiencies between 40 and 50 per cent. This indicates that there is little possibility of reclaiming fine fuller's earth by burning.

There have been a number of methods suggested to reclaim decolorizing materials by the use of solvents, and some of these methods show interesting possibilities. Thus Parsons[2] uses carbon tetrachloride, ethyl alcohol and acetic acid; Chappell[3] uses acetone, methyl alcohol and hydrochloric acid; Rosenbaum[4] uses liquid sulfur dioxide, and Prutzman[5] uses benzol alcohol and water.

Using the constant boiling mixture of alcohol and benzol suggested by Prutzman, efficiencies as high as 90 per cent. have been obtained from individual samples of used Riverside clay. The solvent methods,

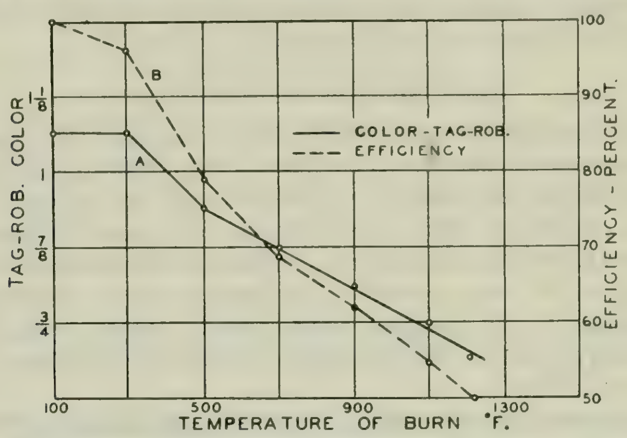


FIG. 7.—EFFICIENCY OF FRESH RIVERSIDE FULLER'S EARTH WHEN HEATED.

therefore, have possibilities of successful development but must still be considered as more or less experimental.

CONTACT VS. PERCOLATION FILTRATION

In order to compare adequately the two methods of filtration, the dual purpose of contacting must be considered. It is an accepted fact that acid treatment followed by contact filtration to neutralize the acid oil gives a superior product to that obtained by acid treatment, chemical neutralization and percolation. Neutralizing by contact filtration overcomes all the emulsion troubles resulting from neutralizing with chemicals and shortens and simplifies the treating operation. The equipment costs but little more than the additional agitator capacity required for chemical neutralizing and the operation is positive and subject to accurate control.

[2] U. S. Pat. 1112650, Oct. 6, 1914.
[3] U. S. Pat. 1488805, Apr. 1, 1924.
[4] U. S. Pat. 1649193, Nov. 15, 1927.
[5] U. S. Pat. 1633871, June 28, 1927.

The contact filter therefore plays an important role in the production of high quality lubricants which cannot be performed by the percolating filter. A comparison of the two methods should, therefore, be limited to decolorizing after neutralization.

In order to compare the two methods let us assume that a given cylinder stock neutralizes by contacting to a color of ½ Tag-Robinson, and the problem involved is to decolorize it to a finished color of 1. This can be done first by using sufficient more clay in the first contact to finish a 1 color. This will require contacting to 1¼ color to allow for darkening during dewaxing and reducing. From Fig. 4 it will be seen that this additional Riverside clay amounts to about 14 per cent. Second, the oil can be finished as ½ color and then recontacted to make 1 color. Fig. 1 shows that this would require 14½ per cent. of Riverside clay. Third, the ½-color finished oil can be percolated through coarse fuller's earth to give 1 color. Experience shows that this requires about 133 lb. of Riverside clay per barrel when using an average clay (1 to 40 burns if a multiple hearth furnace is used).

Table 1 represents the comparative cost of such an operation. The direct expenses cover labor, steam, power, normal maintenance, etc., but do not include plant overhead or investment charges.

TABLE 1.—*Relative Cost of Decolorizing Bright Stock from ½ to 1 Tag-Robinson Color*

	Single Contact	Double Contact	Percolation
Clay used per bbl., lb.	44	46	133
Clay cost per ton	$14.00	$14.00	$20.00
Times used	1	1	40
Net cost per ton	$14.00	$14.00	0.50
Cost burning			0.85
Clay cost per bbl. charge	0.308	0.322	0.090
Cost per bbl. direct operation	0.050	0.196	0.270
Total cost per bbl. charge	0.358	0.518	0.360
Yield finished bright stock, per cent	80	98	98
Cost of decolorizing 1 bbl. finished bright stock	0.448	0.528	0.367

In the first case the extra clay is added at the time of the first contact and therefore carries only a nominal operating expense to cover the extra labor, pressure filtering, etc. However, if the oil is decolorized at this point the 20 per cent. petrolatum content must also be treated, thus materially increasing the cost of decolorizing per barrel of finished bright stock. These costs indicate that, until a method of reclaiming used fine clay or until a relative cheap, highly efficient decolorizing

material is available, the percolating filtration method will prove more economical for final decolorization.

The contact process, however, fills an important role in the production of high quality lubricants which cannot be performed by the percolating filters, and it therefore seems that a combination of the two is the correct solution to the problem.

DISCUSSION

L. B. Smith, Philadelphia, Pa.—Do you notice any relation between the stability of the oil and its acidity?

L. L. Davis.—I assume you mean the acidity before percolation but after contacting. If the correct decolorizing material is used there will be no mineral acidity after the contact filtration. Actually a very small quantity of clay, especially fuller's earth, will neutralize the oil if sufficient steam is used to drive out the SO_2.

H. G. Smith,* Port Arthur, Tex.—What is the decolorizing power of that clay as compared with the Florida clay?

L. L. Davis.—I will answer for contacting and for percolation. In the case of contacting, the Florida clay is a little better than Riverside. In the case of percolating, where a multiple hearth furnace is used, the clays from Texas and from Olmstead are superior to Florida clay for the reason that at the high number of burns the efficiency does not decline as rapidly. For the first 10 burns, or so, the Florida earth is better. Above that, the other clays are better. At 40 to 70 burns, they are very much superior.

H. G. Smith.—My question was directed toward cost per unit of decolorizing potency.

L. L. Davis.—In the Mid-Continent field, especially where we are located, the market price for Riverside, considering freight, makes them competitive.

J. W. Sullivan,† Bayonne, N. J.—Have you done any work on revivification above 1100° F.?

L. L. Davis.—I have worked with both Florida and Riverside, and in general the lowest temperature giving revivification in the time available in the equipment is preferable. At the very high temperatures, for instance take Riverside at 1300° F., the efficiency will decrease very rapidly. With Florida earth, this is even more true.

J. W. Sullivan.—With the type you are working with, did you find 1100° F. is the optimum?

L. L. Davis.—We found in both the experimental multiple hearth furnace and the electric muffle 1050° to 1100° F. gave us the best results.

R. E. Wilson,‡ Whiting, Ind.—Is there a chance of overheating?

L. L. Davis.—In the case of the electric muffle, we controlled the temperature very well because we were able to control amount of air used.

---

* Gulf Refining Co.
† Tidewater Oil Co.
‡ Standard Oil Co. (Indiana).

T. G. Delbridge,* Philadelphia, Pa.—Will you tell us how you test color stability?

L. L. Davis.—Our standard method for determining the decolorizing efficiency of a material is as follows: The batch of oil consisting of anywhere from 200 gm. up to 5 bbl. of oil is mixed cold with the clay by mechanical agitation and is heated as rapidly as possible without foaming over. In the case of a clay carrying much water, such as a pulp, the heating rate is very slow. The temperature is kept below 280° F. until all the water is boiled out. When the foaming ceases, the kettle is covered and superheated steam at 350° F. admitted. The temperature is then raised to the optimum point for the clay in question. The optimum conditions of time and temperature must be determined for each individual clay and oil. After the temperature and time period has been reached, the oil is cooled down under steam to 300° F. when the kettle is opened and the oil filtered.

T. G. Delbridge.—My question referred to the stability of the color.

L. L. Davis —The stability curve was made at 140 degrees.

T. G. Delbridge.—In glass?

L. L. Davis.—In glass, open to the air, in ordinary room light.

L. B. Smith.—Has any determination been made with iron in the oil?

L. L. Davis.—We do not use any of the metals in our test. I wish, though, someone would develop a standard method along that line.

T. G. Delbridge.—L. B. Smith and his associates have employed a test, using glass as a container, with or without exposure to air, in the presence of a rusty iron nail and also in the presence of water. We were misled at one time in that by carrying out the heat test in glass only, the oil apparently stood up but went off in tankage. Therefore, we believe that if a standard test is developed, it should include the presence of moisture, iron rust and iron itself.

L. L. Davis.—Our experience indicates that our 30-day tests will show us whether our oil will go off color in storage.

T. G. Delbridge.—That is too long a period for a practical test.

* Supervisor, Process Division, Atlantic Refining Co.

The Acid-sludge Problem in Oil Refining

By J. B. Rather,* New York, N. Y.

(New York Meeting, February, 1928)

The use of sulfuric acid in refining illuminating oils antedates the beginning of the petroleum industry in America by many years. It was used as early as 1792 by Tower in refining "coal oil" in the British Isles, and by 1860 there were 53 refineries in the United States manufacturing "coal oil," most of them using sulfuric acid as a refining agent. Following the completion of the Drake well in 1859, many of the "coal oil" refiners began to use petroleum for manufacturing illuminating oil, and their methods and equipment were adapted so far as possible to this new raw material. The value of sulfuric acid in refining "coal oil" having been established, this reagent was immediately tried and found to be satisfactory in refining petroleum. Notwithstanding the tremendous advances in petroleum technology since that time, sulfuric acid remains today the most valuable and most widely used means for refining petroleum products.

Early Methods of Disposal of Acid Sludge

With the almost immediate expansion of the petroleum industry came the problem of disposing of the acid sludge produced in the refining operations. While in 1859, the year of the discovery of the Drake well, a patent was granted for sludge separation and separated acid concentration, most of the earlier refiners, and many of their successors, felt that separation and recovery of spent acid was uneconomical. Accordingly, many of them disposed of the sludge in any way that seemed expedient at the time. It was buried in the refinery grounds, barged and dumped at sea, run into neighboring streams, or dumped into sewers. Some optimists carted it to open pits in the hope that it would either sink into the ground or evaporate. Not so many years ago, the superintendent of an eastern refinery, who was using the open-pit method of disposal, lost a sludge cart, with horse attached, in such a pit. The horse was recovered almost immediately, but its availability for further use was reduced to zero by the loss of its hair.

* Standard Oil Co. of New York.

Those of us who are familar with subsurface conditions in the older refineries know that excavations for foundations for refinery structures are very likely to lead to the discovery of a long-forgotten sludge deposit.

At a western plant, where the amount of acid sludge was not large, for a time it was disposed of by dumping into city sewers. The success of this method was more apparent than real, for the city authorities, noticing unusual conditions, traced the difficulty to the refinery. Everyone was able to take cover except the refinery foreman, who had to explain his action in court, and later to meditate in jail for a short time.

Another simple method of disposing of acid sludge used by an eastern refinery some 30 years ago, consisted in the erection of a 500-bbl. tank on a dock located on a navigable stream, with a draw-off pipe running through the dock into the water beneath. During the day the sludge was pumped into the tank and at night, just before leaving, the chief oil treater would open the valve leading to the water beneath the tank. The next morning the tank was empty and the cycle was begun all over again. This practice was followed for a number of years until it became evident that other means of disposal would have to be adopted. Even then it was felt that the ocean was the best place for sludge and it was barged out to sea and dumped.

Another refiner pumped his sludge to a sump located on a hillside. The level of sludge in the sump remained constant and the problem of disposal was regarded as solved. A few months later it was found, however, that much of the acid was finding its way to a lake in a neighboring valley, and another method of sludge disposal had to be found.

It is interesting to compare these early methods of sludge disposal, which were frequently based on an entire disregard for the rights of the community, with the modern practice, especially as regards water pollution, on the Atlantic seaboard. At one refinery, where all waste waters were discharged through a private sewer into a bay, samples of the water were taken direct from the sewer at 30-min. intervals for a period of several years. These samples were analyzed for acidity on the spot, and the acid concentration was kept, by dilution, to a very few parts per million. At this refinery, and a number of others in the same section of the country, the waters adjacent to the plants are constantly patroled, and any oil or tar, whether resulting from sludge or otherwise, is skimmed off the surface of the water by hand. Elaborate and highly efficient trap systems have been developed and the precautions taken today to prevent pollution in a number of localities would be beyond the comprehension of the refiner of an earlier generation.

Development of the Separation Process

It is interesting to note that in the same year as the Drake discovery (1859), a patent (U. S. 24952) was granted to Henry Pemberton for a

method of treating acid sludge. While this patent applied principally to sludge of bituminous origin, reference was also made to acid sludge from petroleum distillates. The proposed process consisted of:

1. A preliminary heating to obtain a separation of the free sour oil.
2. Agitation of the acid-sludge residue with hot water and open steam.
3. Separation of weak acid and tar.
4. The recovery of acid by evaporation of the weak acid in lead pans.

The patent is particularly significant inasmuch as the process formed the basis for a majority of the later patents. The Pemberton patent was followed by somewhat similar ones by Loftus in 1864, by Penissant in 1878 and by Farrar and Gill in the same year. These three patents form the foundation on which all modern practice of acid separation and recovery is based. Since that time many patents have been issued, a few of which are mentioned below, but practically all of them utilize the basic procedure of diluting with water, agitating and settling.

Bower, in 1880, recovered sulfuric acid by washing the sludge with water in covered tanks and mechanically separating the acid solution from the carbonaceous matter and oily ingredients. Breinig, in 1884, mixed with the sludge a soap compound adapted to unite with the tar, and separated the free acid from the tarry mass. J. L. Gray, in 1909, claimed the production of pitch and asphalt from petroleum sludge by digestion with water, steam, or dilute acid recovered from the sludge, until the major portion of the acid had been recovered. The tar, comparatively free from acid, was heated with a steam spray until the mass was converted into pitch. Another of Gray's patents covered a process in which the acid sludge was digested with water, air, and steam, until the light constituents rose to the top. These were drawn off, and the digestion continued until a second grade had arisen. A heavy residuum was drawn off from the bottom of the separator, and the weak acid finally separated.

Schildhaus and Condra, in 1910, heated acid sludge to 200° to 300° C. and at the same time introduced air into the retort at about the same temperature. The liquid hydrocarbons were distilled and condensed, and the gases, consisting largely of sulfur dioxide, were washed first with heavy hydrocarbon oil and finally with sulfuric acid. No better means of producing sulfur dioxide from the materials at hand could have been thought of.

Van Tienen, in 1911, appears to have been among the earlier inventors making use of both heat and pressure for sludge separation. He recovered hydrocarbons and sulfuric acid from sludge by mixing sufficient water with it to dilute the acid to 52° Bé., and heating the mixture to a temperature of 140° to 165° C. at a pressure of about 100 lb. per sq. in. The liquid was separated into two layers, one containing sulfuric acid and the other containing tar.

A type of separation for sludges from so-called "paraffine" lubricating oils, largely used in the past, and still the most desirable under certain conditions, consists in cooking the sludge, without dilution with water, with open steam in a cone-bottom, dome-top lead-lined agitator, equipped with a scrubbing device for taking care of the sulfur dioxide and other vapors evolved. The cooking is carried on for several hours, after which the batch is allowed to settle into three layers, acid of about 45° Bé., pitch, and acid oil. The acid and acid-oil layers are drawn off and the pitch layer is fed to a screw conveyor, where it is subjected to a spray of cold salt or fresh water. This operation transforms the pitch into coke-like particles of about ½ to 1 in. diameter, which can be handled and burned under boilers or stills like coal.

This method has not proved altogether satisfactory, on account of the difficulty of transporting the acid coke or pitch and the corrosive action on equipment when burning. The more recent installation of specially designed fireboxes and burning equipment has increased efficiencies in this connection.

An alternative practiced in some refineries consists in the neutralization of the acid coke with alkali after separation of the weak acid. The product in this case is liquid, pumpable and may be burned to advantage in the usual fuel-oil equipment. It is sometimes necessary, however, to add gas oil before burning, to lighten the consistency.

Forms of Separators

The first form of separator was nothing more than a tank provided with means of agitation and suitable connections for withdrawing the acid and oil. This type of separator was adequate as long as gasoline and kerosene from paraffin-base crudes were the only products. The light character of sludges from these sources made the separation problem a simple one. It was soon found, however, that simple agitation with water would not serve to separate lubricating oil sludges, and accordingly open steam pipes were introduced into the separators. With other types of sludges, notably those obtained from fuming acid treats of napthene-base kerosene distillates, it became necessary to cook many hours with steam under a pressure of several atmospheres.

All of these types of separators were intermittent, or "batch," separators. Continuous separators are a more recent development. Heckenbleikner, in 1926, patented a separator consisting of a "closed pressure container, having an exterior acid-proof lining and an interior refractory facing for the lining." Suitable lines and tanks necessary for accomplishing the continuous separation of the acid sludge and its constituents are provided. An eastern refiner uses a simple device for separating in a continuous manner the sludges obtained from 66° acid treatment of gasoline and kerosene distillates. This separator operates

without external heat and without pressure. It delivers a separated acid of constant gravity and requires practically no attention.

Separators may be of almost any size, from 50 to 500 bbl. capacity, depending on the amount and nature of the sludge available and on whether or not the separated sludge is to be fluxed in the separator. A typical batch separator for light oil sludge consists of a lead-lined, cone-bottom and cone or dome-roofed tank, equipped with water and air lines and sludge intake and draw-off connections. Frequently it has means of scrubbing the air as it goes out of the separator, in order to remove the sulfur dioxide which is invariably evolved in considerable quantities.

Separators for certain types of Pacific Coast light oil sludges are practically autoclaves capable of withstanding a pressure of 100 lb. per sq. in., or more, in which the sludge is cooked with water and steam for several hours.

Where light oil and lubricating oil sludges are available in the same plant, they are frequently combined before the acid-separation process, and the resulting mixture of pitch and acid oil is fluxed with heavy fuel oil. In general, separators for this purpose are of conventional design, as described above.

Development of Acid Concentrators

Many of the earlier refineries had sludge-acid separation plants but were not equipped for acid concentration. The separated acid was sold to other refiners equipped to concentrate acid, or to manufacturers of acid phosphate intended for fertilizer, or disposed of by dilution with sea water, where that was available.

Concentration methods were given attention by inventors at an early date. Both Loftus, in 1864, and Penissant, in 1878, described methods for concentrating separated acid. Gronsilliers, in 1888, added sodium sulfate to the separated acid and the bisulfate was precipitated by boiling and evaporating. The precipitate was dried and the acid recovered by heating at a moderate red heat. Waring and Breckenridge mixed about 4 per cent. of sodium nitrate with sludge acid at a temperature between 60° and 180° F., to purify it and permit the recovery of the sulfuric acid. A foreign patent of interest is that of the Steaua Romana Petroleum G. m. b. H., in which the separated black acid was allowed to flow continuously into pure boiling concentrated sulfuric acid in the presence of an oxidizing current of air, the evolved acid vapors then being condensed and reconcentrated in standard apparatus.

The common American practice in sludge-acid concentration up to about 1920 consisted in concentrating to 60° Bé. in lead pans, and finishing to 66° Bé. in cast-iron pans or glass retorts. The lead concentrating pans commonly employed varied considerably in size in the different

plants. According to Day, units 5 ft. wide by 50 ft. long and 10 in. deep, as well as a series of shorter pans of the same width (15 to 20 ft. long) were not uncommon. Such pans were generally constructed of 10 lb. chemical lead, and supported by perforated cast-iron plates laid over the furnace flues. Heat for concentration was frequently supplied by combustion of the separated acid oil.

The acid left the last compartment of the pan, or the last pan of the series at about 60° to 62° Bé., and passed to a series of two cast-iron pans, or "stills," generally about 4 by 8 ft. by 10 in. deep, provided with hoods lined with acid-resisting material, leaving the end pan at a temperature of about 450° F. and a gravity of about 66° Bé. The vapors were usually condensed in a scrubber and the weak acid returned to the system. The life of these castings was very short, averaging in one western plant about six weeks, and failure of the pans frequently resulted in the loss of appreciable percentages of acid.

Increased efficiency in operating pan plants was said to be obtainable by bubbling air through the acid, and by cascade systems of fused silica basins. However, while a "pan and still" plant was built on the west coast as late as 1920, and while many such plants are no doubt still in use, the trend in the last seven years has been away from such methods of concentration.

In a number of refineries, particularly in the East, the final concentration of the acid was conducted in glass retorts or "bottles," holding about 750 lb. of 62° Bé. acid. This type of installation also delivered acid of 66° Bé. strength. When the bottles were carefully set and properly handled, the loss in breakage in a bottle plant was said to be small. However, the operation was intermittent or "batch," instead of being continuous, as was the case with the pan or "still" system, and the fuel cost was high. Furthermore, this method of final concentration was decidedly dangerous. There was no way adequately to test a "bottle" before it was put into service, and the failure of a bottle frequently resulted in dumping 700 lb. or more of concentrated acid at a high temperature on the floor of the bottle house. Refinery superintendents and foremen showed an entirely justifiable lack of interest in what was going on in the bottle house, and their inspections of operations frequently consisted in going in at one door of the house and out the other as rapidly as possible.

Systems of Concentration

The first plant on a semi-commercial scale for the continuous concentration of acid by bubbling hot flue gases through it was erected at Brooklyn in 1919, and the first fully commercial plant of this type was erected at Buffalo, N. Y., during the next year. This was followed by an installation at Providence, R. I., a short time later. Many such plants are scattered through the United States today.

This type of sludge-acid concentration is known as the Chemico process, and is based on the fact that when a mixture of hot air and flue gases is passed through the liquid to be concentrated a substantially lower temperature may be carried than is required for pan concentration. In addition, heat transfer is better, and fuel costs correspondingly reduced. The total operating costs, including fuel, labor, general expenses and repairs, losses and royalty, is said to be fully 50 per cent. lower than with the pan and still system.

Another system of sludge-acid concentration, known as the Simonson-Mantius process, is based on the principle of vacuum distillation, with its well known advantages. The first plant of this type was erected at Paulsboro, N. J., several years ago, and a number of other plants of this kind have been put into operation since that time.

A more recent development is the Geyser system. This process resembles the Chemico process in that hot flue gases are used to supply the heat needed for evaporation of the water, but differs from it in that the evaporation is accomplished by blowing the flue gases across the surface of the liquid, which is kept in a violent state of ebullition by means of an independent stream of air.

The Chemico and Vacuum processes are two-stage systems, in which the first concentration is to 60° to 62° Bé., and the final concentration to 66° Bé. The Geyser system is a one-stage process.

While great progress has undoubtedly been made in reducing the cost and nuisance of sludge-acid concentration, the nature of the material to be handled is such that this part of refinery operation still remains a troublesome and expensive procedure.

Disposal of Sludge by Burning

The solution of the sludge-disposal problem by burning the sludge has probably been attempted at one time or another by almost every refinery superintendent. Burning the sludge direct, without separation or fluxing, has been practiced to a certain extent. Burning after fluxing, without separation of acid, has also been tried. Burning after separation, either with or without fluxing, and burning the "coked" separated sludge, have been practiced for a long time.

At a large refinery on the Pacific Coast it was formerly the practice to burn lubricating oil sludges under boilers without any preparation whatever except separation of the loose acid. In order to facilitate combustion, the boiler furnaces were fitted with Dutch ovens, which reduced to a very considerable extent the tendency to throw unburned agglomerations of soft carbon out through the stacks. Of course, in such a system all of the sulfuric acid in the sludge went out the stacks as acid or as sulfur dioxide and possibly trioxide, and it would not be possible to practice

such a method of sludge disposal except in localities where the neighbors were few.

At one plant in the Mid-Continent field, partly neutralized sludge is mixed with about 20° A. P. I. fuel oil and burned in a specially designed burner with a vibrating valve stem. This type of sludge burning has been tried elsewhere and with varying success, depending on the nature of the sludge at hand.

The operation and maintenance of such systems as the above are both troublesome and expensive. Acid-resisting lines and pumps have to be provided, and even when the sludge is kept circulating all the time, line plugging is frequent.

Burning separated sludges from gasoline and kerosene treats from stock of Mid-Continent origin is relatively a simple matter. Such sludges are generally fluid enough to burn without fluxing, although there is frequently a certain amount of pitchlike material which cannot be pumped conveniently.

At one time, in an eastern refinery, sludges from the treatment of crude oil intended for cylinder stock were fluxed after the separation of the acid. Fluxing was done with heavy Mexican fuel oil with the aid of open steam in separators of about 500-bbl. capacity. The fluxed sludge was then pumped about 1000 ft. to a boiler house and burned. This system worked in a satisfactory manner as long as the sludge was separated and fluxed within 24 hr. after it was produced. If allowed to "ripen" for several days before separation was attempted, it was almost impossible to secure adequate separation of acid or a satisfactory fluxed fuel.

The method of coking lubricating-oil sludges has been described above under methods of sludge separation. For types of sludge that respond to this treatment, this is probably the best way to handle the problem. This is largely due to the fact that sludges that may be coked readily are very difficult to flux, and vice versa.

The proper method of disposal of sludges is very largely dependent on local conditions and each refiner has a different problem to solve. We do not have, and probably never will have, a single method of sludge disposal that is applicable to all conditions.

The Fume Nuisance

Very early in the history of the petroleum industry, petroleum refineries were confronted with the fume-nuisance problem, and about 1858 Col. C. A. Ferris, of New York, was "forced to move his plant because his neighbors objected to the strange and unsavory odors caused by the distillation and refining of oils." At the present time the disposal of sulfur dioxide and other fumes resulting from the separation and concentration of sludge acid is a problem of some magnitude. As early as 1880, E. Clark obtained a patent for a procedure for recovering spent acid from

acid sludge, in which the offensive vapors were conducted off by an exhaust produced by an induced steam blast while the sludge was agitated with steam.

Fumes, particularly sulfur dioxide, may be evolved at a number of points in treating, separating and concentrating. Batch treatment of lubricating oils is a prolific source of sulfur dioxide, especially when that gas has to be blown out of the oil by air prior to contact clay application. Closed continuous-treating systems for lighter oils are, of course, free from this nuisance. Sludge separators of the batch type are also large producers of sulfur dioxide, especially when the sludge has had a chance to "ripen" before separation. The volume of sulfur dioxide evolved from sludge from 66° acid treatment of gasoline and kerosene distillates was found in one case to be eight times the volume of the sludge when the latter had been allowed to stand only 24 hr. before separating. Batch lubricating oil sludge separators, where steam has to be used to effect separation, also add to the quantity of sulfur dioxide produced. Sulfur dioxide also inevitably accompanies any attempt to burn acid sludge direct, or after fluxing, or to burn fluxed or unfluxed residues of separated sludge or solid sludge.

The most prolific source of sulfur dioxide, however, is the acid-concentration plant. The old pan-and-still systems were notorious in this respect. In the Chemico type of concentrator, in the earlier installations, the fumes were scrubbed in packed towers with water. The more recent installations, however, use the Cottrell electrical precipitator. This type of scrubber has the advantage of higher exit temperature for the gases, but any sulfur dioxide not present in solution in water will still pass out to the air. Nevertheless, the Cottrell precipitator reduces the visible fumes enormously. The fumes resulting from the concentration of acid by the Simonson-Mantius vacuum process are taken care of by the water jet condenser which furnishes the vacuum for concentration. This is theoretically advantageous, for the reason that the sulfur dioxide is not mixed with a large volume of inert gases before scrubbing is attempted.

The fume nuisance in batch treating of lubricating oil has been eliminated at some points by putting an exhauster on the agitators and leading the fumes to a high boiler stack. Fumes resulting from batch separators may be minimized to some extent by means of steam or water jet condensers, and the amount of sulfur dioxide produced can be reduced materially by separating the sludge as soon as produced.

In the disposal of sludges and sludge residues by burning under boilers and stills, distribution of the operation evenly throughout the day is desirable, in order to reduce the concentration of sulfur dioxide in the air at any one time as much as possible. At one point where "acid coke" was being burned under stills with coal, it was necessary to limit the percentage of this material to 20, or below, in order to reduce air pollution to a satisfactory point.

It should always be borne in mind that the higher the stack and the higher the stack-exit temperature, the less chance there is for trouble from these sources. It should also be remembered that it is not the amount but the concentration of sulfur dioxide in the air which leads to complaints from neighbors.

Such complaints are of two kinds. The neighbors may object to the odor of the gas, or gases, and they may claim damage to vegetation. Sulfur dioxide in sufficient concentration will damage vegetation, and a number of refiners maintain a vigilant patrol of the air of the neighborhood in order to reduce complaints of this sort to a minimum.

Substitutes for Sulfuric Acid

One way to handle the refinery acid-sludge problem is not to make the sludge. A number of substitutes for sulfuric acid have been suggested from time to time, but the majority of these are only auxiliary aids to sulfuric acid in refining petroleum products. Among these may be mentioned materials that depend upon certain absorptive properties for their usefulness in refining operations. Clay, bone char, activated carbon and silica gel are representatives of this class. These materials can either be used in relatively coarse particles in percolation filters or in a finely divided state by the so-called contact method.

Another class of materials suggested as substitutes for sulfuric acid are certain solvents, such as liquid sulfur dioxide, analine and methanol in admixture with certain aromatic hydrocarbons. These materials owe their refining value to their selective solvent action on certain constituents of the oil which are undesirable in the finished product.

The Edeleanu process, which involves the extraction of the aromatic hydrocarbons by the use of liquid sulfur dioxide, is the only one of these that deserves more than passing mention. This process was particularly designed for the production of good burning oils from certain Rumanian crudes, but it is applicable to other products, especially those requiring fuming sulfuric acid for adequate treatment. The Edeleanu process is in use on a commercial scale at a number of points in the United States, particularly on the Pacific Coast, and it is probable that it will fill a definite need in American petroleum technology.

Another type of refining process applied commercially in recent years is the Gray vapor-phase clay process. This has been applied commercially both at Mid-Continent and eastern refineries, principally on cracked gasolines.

Except under very limited conditions, none of the above processes, with the possible exception of the Gray process, make it possible to dispense with the use of sulfuric acid completely. Sulfuric acid still has to do the heavy work in refining, and the sludge-disposal problem is like the poor, it is always with us.

DISCUSSION

L. L. Davis,* Ponca City, Okla. (written discussion).—We feel that Dr. Rather's excellent summarization calls for no comment except insofar as our own experience along this line may prove of interest. The Marland Refining Co.'s acid sludge problem calls for the disposal of 115 tons of lubricating oil and 15 tons of light oil acid sludge per day.

Our practice is to separate the acid in the conventional type of open cooking kettle. The proper mixture of gas oil or other fluxing oil, water, light oil sludge and lube oil sludge is cooked with live steam until separation takes place, and then settled. It has been found that a careful laboratory control of the process, particularly of the gravities of the component parts of the mixture, assures uniform and satisfactory results.

The cooked sludge settles into three distinct layers. The lower layer consists of the weak acid which is drawn first, and is then charged to the Simonson-Mantius concentration plant. The upper layer is a liquid acid fuel oil, which is easily handled in the circulating fuel system for firing the distilling equipment.

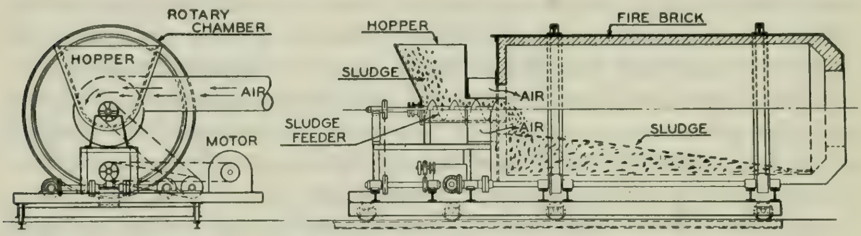


Fig. 1.—Sludge Burner.

The middle layer consists of the so-called acid "coke" and presents the most difficult problem. It is soft enough while hot to flow and can be drawn as a plastic mass from the kettles, but when cool sets to a brittle solid which will not soften on reheating. Up to two years ago our practice was to impound this material. Since then we have successfully adapted chain grate stokers to handle it. The acid "coke" is mixed with half its weight of petroleum coke breeze from the cracking stills and the resulting mixture is charged in the usual manner to the chain grate stokers. We have two 100-sq. ft. stokers under 550-hp. boilers and have been able to maintain ratings of from 140 to 160 per cent. with this fuel. However, the maintenance problem is severe as the clips burn out frequently due to difficulty in holding a uniform distribution of fuel and air over the entire grate.

Recently a new type of burner has been developed by Wm. M. Duncan and placed on the market by the Illinois Stoker Co., which shows excellent possibilities in handling both solid and liquid waste fuels. Burners of 500, 1500 and 3000 lb. per hr. have been built and are operating under stills and boilers. Excellent fuel economy is obtained, the flue gases giving from 8 to 11 per cent. CO_2 content.

We are now installing a Duncan burner designed to handle 4000 lb. per hr. of solid acid coke, under a 550-hp. boiler. The burner itself (Fig. 1) consists of a cylindrical shell 7 by 16 ft. in size overall, firebrick lined, mounted in a substantially horizontal position on two annular runners resting on four trunnions. In appearance the burner resembles a small rotary kiln. A driving mechanism revolves the entire retort on trunnions.

* Assistant General Superintendent, Marland Refining Co.

The fuel is fed into one end of the burner by means of a variable speed screw conveyor. Continual agitation is given the fuel mass by the rotation of the cylinder. In this way the fuel is brought in contact with the hot lining and gas is evolved which readily ignites, insuring continuous combustion. Air, under forced draft is admitted around the feed screw in a radial direction so that the fuel mass is completely consumed. Sufficient air may be used in the burner proper to give complete combustion, or if preferred, the burner can be operated as a gas producer and the combustion completed under the boiler or still with secondary air.

The complete installation (Fig. 2) will consist of the burner as described above, a chain drag conveyor to transfer the sludge from a storage hopper to the burner feed hopper and an overhead crane and clamshell bucket for handling the sludge from the drain pits to the storage hopper. Although the burner is still in the development

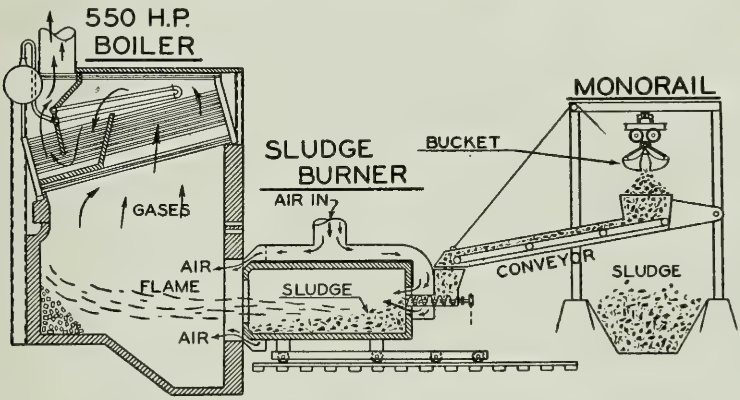


Fig. 2.—Sludge burner instalation.

stage, we feel that it is a valuable contribution to the refining industry and may prove to be a solution to the acid sludge and waste oil disposal problem.

W. Miller,* Ponca City, Okla.—The rotary burner cited by Mr. Davis is to my mind the most efficient solution of disposal of acid coke. The burner itself is expected not only to take care of the sludge coke but to handle plastic and semi-plastic material as well as solid. There is one in active operation at Wood River, Ill. The few difficulties encountered have been remedied. Marland expects in about six weeks to have one in operation on a somewhat larger scale.

E. W. Isom,† New York, N. Y.—Are there any figures as to the efficiency of the rotary burner?

L. L. Davis.—The efficiency is a difficult thing to determine, because of corrections for the amount of water and acid in the sludge itself. But the fact that they can operate regularly with CO_2 at 8 to 10 per cent. would indicate they are obtaining relatively good efficiencies.

E. C. Higgins.—I will mention some experiences we have had in separation and in quality of weak acid. We have found that due to the recent advance and excessive manufacture of anti-knock gasoline, the quality of weak acid appears to be inversely proportional to the quantity of anti-knock gasoline which we are manufacturing. As

* Vice-president, in Charge of Refining, Marland Refining Co.
† Sinclair Refining Co.

a matter of fact, in separating sludges which have been manufactured from highly unsaturated pressure distillates from the various cracking processes, we have found that the weak acid contains anywhere from 5 to 15 per cent. of organic acids, whatever they may be.

I believe that in addition to the sludge disposal problem, in the next 2 or 3 years, with the advent of anti-knock gasoline, we shall face the problem of finding a method to remove these organic acids before concentration.

Recovery of Gasoline from Refinery Gases

By George A. Burrell,* Pittsburgh, Pa.

(New York Meeting, February, 1928)

[The author was unable to present his paper. His general conclusions presented in writing are as follows.]

A gasoline recovery plant at a refinery is usually considered such a profitable investment, and performs so well apparently, even under conditions of low efficiency, that frequently but little attention is given it to make it perform at top efficiency. Further, there are so many other units in a refinery that demand most of the available attention that the recovery plant is left to shift for itself. "It seems to be doing pretty well so why bother with it," is sometimes the attitude toward it. On the other hand, there is no reason why it should not be placed on the same high plane of efficiency as that of many natural gasoline plants. The two problems, gasoline recovery from natural gas and gasoline recovery from refinery gases, have much in common.

At some refineries the gasoline recovery plant produces too much gasoline, because too low a pressure is carried on the gathering lines and the condenser boxes are robbed of gasoline that they can and should take care of, and as a consequence the refiner fools himself into believing that his recovery plant is an extraordinarily fine unit, when on the contrary it may be working at low efficiency insofar as doing its rightful job is concerned.

* Burrell-Mase Engineering Co.

PRODUCTION

Production Development in 1927

By W. E. Wrather,* Dallas, Texas

(New York Meeting, February, 1928)

The overproduction of crude oil in 1927 has received such widespread publicity, both within and without the industry, and the several factors which have brought about this situation are so thoroughly agreed upon by everyone, that it is unlikely the writer will in this brief review be able to contribute anything new. The entire story of low prices and demoralization revolves around two flush districts, Seminole and West Texas—the actual performance of Seminole and the potential threat of West Texas. The sustained production of California has been a contributing factor to this situation also. It seems reasonably certain that Seminole and West Texas will together dominate the industry during 1928, with Seminole probably destined to drop into second place, as additional pipe lines are completed into West Texas to care for its rapidly expanding production.

It now appears inevitable that the production of 1928 will equal or exceed that of the past year, depending solely upon the rapidity with which it is possible to market West Texas crude, and the degree of restraint which operators are willing to impose upon themselves in holding proved reserves of oil underground. Adversity has cultivated the growth of a promising spirit of cooperation which has accomplished practical results both at Seminole and in West Texas. Cooperation among oil producers has long been ardently hoped for, but prior to the past year it has never been effective on an important scale. The interests both of the industry and the public at large can best be conserved by cooperation in controlling production, and the widespread acceptance of this idea has paved the way for a more rational policy in the immediate future.

Production by Major Districts

The domestic production of the United States during 1927 amounted to 894,435,000 bbl. (Bureau of Mines), an increase over 1926 of approximately 128,000,000 bbl. California succeeded in maintaining its position of the past four years at 230,000,000 bbl. In 1923 with the Los Angeles

* Consulting Geologist.

basin fields at their peak, California production mounted to almost 264,000,000 bbl., but in subsequent years it has maintained substantially an even figure with slight annual variation. If shut-in production had been run open for 1927 it is more likely that California would have equaled the peak of 1923. Texas jumped from 172,500,000 bbl. in 1926 to 220,-000,000 bbl., an increase of 47,500,000. The production of West Texas fields, exclusive of the Panhandle, was approximately 50,000,000 bbl., which indicates that the state barely held its own except for this new supply. Oklahoma increased from 177,650,000 to 276,000,000 bbl., a gain of almost 100,000,000 bbl. Greater Seminole alone produced 136,-000,000 bbl., from which it is evident that the state failed to maintain its position by some 36,000,000 bbl., aside from the production of this district. A correct analysis of the year's production is of course not so easily arrived at, but these figures serve to indicate roughly where the surplus oil was produced. The deviations from 1926 figures in other producing states were not of substantial consequence in relation to the production of the entire country, and in any general analysis, may be disregarded.

At the end of 1927, the Bureau of Mines reported storage oil east of California at 351,646,000 bbl., to which must be added 113,000,000 bbl. refinable and heavy crude on the Pacific Coast, making a rough total of 465,000,000 bbl. This represents an increase in stocks of crude during 1927 of better than 67,000,000 bbl. The stored crude oil above ground therefore represents slightly more than a 6-months' supply exclusive of stocks of refined oils on hand. In addition to domestic production, 58,156,000 bbl. of crude were imported, of which amount 26,000,000 bbl. came from Mexico, better than 21,000,000 bbl. from Venezuela, and approximately 8,000,000 bbl. from Colombia. In other words, imports fell short by less than 10,000,000 bbl. of equaling the amount of excess domestic production run to storage during the year. It is evident that during 1928 Venezuela will definitely supplant Mexico as our chief reliance for foreign oil in the future.

Seminole

The several pools comprising the Seminole district are situated in Townships 8 and 9 North, Ranges 5 and 6 East, in Seminole and Pottawatomie Counties. These pools in the order of their importance are Seminole City, Bowlegs, Earlsboro, Searight and Little River. All but the latter field were discovered during 1926. The areal extent of the several pools may be roughly estimated from the number of producing wells, allowing one well to 10 acres. On Feb. 10, 1928, Seminole City had 318 wells or 3180 acres; Bowlegs, 307 wells, 3070 acres; Earlsboro, 290 wells, 2900 acres; Searight, 71 wells, 710 acres; and Little River, 95 wells, 950 acres. This indicates a total productive area of 10,810 acres, which is somewhat higher than other estimates which give around 10,500 acres

for the combined pools. All the oil outside the production from the Earlsboro sand, which is of Pennsylvanian age, comes from the Simpson or Wilcox sand, of Ordovician age.

Seminole City is the only pool which made a substantial production in 1926. On Jan. 1, 1927, this pool had 123 producing wells and had produced 10,838,823 bbl.; and Earlsboro had 11 wells which had produced 388,460 bbl. Searight, then carried as part of Seminole City, had 13 wells; Bowlegs 2, and Little River had not yet been opened. During 1927 the Seminole district produced 135,951,098 bbl., or from its inception, approximately 147,000,000 bbl., which would give an average yield per acre to date of around 14,000 bbl. (on the basis of 10,500 acres). Seminole City on account of its longer life and also because of better sand conditions had produced until the first of the present year, about 18,200 bbl. per acre, although earlier in the year certain prolific tracts had made over 40,000 bbl. per acre. It should be borne in mind that these statistics cover approximately one year's production and that they are the result of an application of the air-gas lift on a scale hitherto unknown in the oil industry.

The future of the Seminole district is to a considerable extent contingent on the outcome of several prospective areas which are by agreement temporarily held in check. There are in all seven isolated shut-in wells in the general area which have made substantial amounts of oil from the Wilcox sand on short tests. Four of these wells lie in the southward extension of the principal production trend indicated by the alignment of Searight-Seminole City-Bowlegs-Little River; and three are in the area situated south of Earlsboro and west of Bowlegs and Seminole City. Little River has been the least satisfactory of the several pools. Its spotted character is attributed, at least in part, to greater complexity of subsurface geology. It is the most southerly of the several pools and is situated nearest the mountains in which the general structural situation is thought to have its origin. Complexity of structure may reasonably be expected to increase as the "Seminole plateau" approaches the mountains. The importance of the four wells south of Little River has therefore been discounted. But it is thought that there is ample room for a pool of major proportions somewhere in the area south of Earlsboro.

Since from three to six months is here required for development in a new area to assume importance, it is obvious that new oil from these several prospective localities cannot be produced in quantity before midsummer or later, in view of prevailing shutdown agreements; and in the meantime old production will be steadily declining. It may be noted in passing that the older pools are showing unexpected "staying qualities" and that the decline is not so rapid as was expected. It is possible also that the shutdown agreements may be extended from time to time, if the general situation fails to improve. The Seminole outlook

is therefore fraught with several uncertainties, and its influence on the general situation throughout the next few months cannot be forecast with any assurance.

West Texas

The potential possibilities of West Texas increased by leaps and bounds during 1927. This area includes of course, the South Plains, and does not include the Panhandle or North Plains district. In 1926 West Texas produced approximately 16,500,000 bbl. and closed the year with a daily average of 62,800 bbl. This production came from the Big Lake, McCamey, Church-Fields-McElroy, and minor pools in Mitchell, Howard and Crockett Counties. The Yates and Hendricks pools had been discovered but at the end of 1926 the former had two producing wells, and the latter only one. At the present time these two pools overshadow the development in this section and bid fair to take place among the most remarkable pools of the Mid-Continent.

Daily production in West Texas amounted at the close of 1927 to 260,750 bbl., which represents merely the capacity of existing transportation facilities. Estimates of the developed potential production vary anywhere between 500,000 and 1,000,000 bbl. per day; but too much dependence cannot be placed on any such estimates, which represent merely opinions of the capacity of wells which have never been given a sustained production test. It seems however that the smaller estimate is entirely reasonable.

This production is practically all a high-sulfur crude, ranging in gravity from 30° to 38° Bé. The producing horizons occur throughout the upper 1000 ft. of the "Big Lime" of Permian age. The Yates production comes from the upper 200 ft. of the lime as does also that of the McCamey, Church-McElroy and the upper pays in the Hendricks pool. Pay horizons have been found at Hendricks at over 600 ft. in the lime, and recently completed wells in the Chalk pool of Howard County are 850 ft. below the top. Substantial showings have been found at even lower stratigraphic horizons, and at this time it is by no means certain that deeper horizons than those now known may hold important reserves.

While the vertical range of production is not now known, neither is the horizontal. Important pools are now developed in 10 counties and several others seem to offer promising prospects. Wide expanses of untested territory are scattered throughout this area and it is a reasonable assumption that other major pools remain to be discovered. It is also true that few of the principal producing pools are completely defined. During the closing months of 1927 a remarkable expansion of the Hendricks pool in Winkler County has been proved. In fact the significance of this situation seems to lie in the fact that we are here dealing with true Rocky Mountain structure, buried beneath a veneer of Upper

Permian and Cretaceous sediments—structure of a magnitude which has seldom proved productive in the United States.

The yield in the McCamey field has been disappointingly small despite the fact that certain leases are reported to have made better than 15,000 bbl. per acre. In the Church-Fields pool several adequately developed small tracts have made better than 30,000 bbl. per acre. In the Big Lake field, a considerable contiguous area has yielded better than 23,000 bbl. per acre, but many geologists insist that this may not prove to be a typical West Texas field, due to its isolation and the peculiar oolitic character of the pay horizon. The McElroy pool has not been drilled intensively, though it is estimated that 25,000 bbl. per acre may not be excessive for a large part of the acreage. In the Yates pool, on the northeast flank of the structure, four distinct prolific pay horizons have been recognized throughout 150 ft. or more of the upper portion of the lime, and it is not known that any wells have been drilled to greater depth to determine whether the pay zone has been completely penetrated. Bottom-hole pressures average around 700 lb. Edge water has been found at the east and west extremities of the structure at approximately the same elevation above sea level. Between the water level and the summit of the subsurface structure there is some 285 ft. of structural relief, involving according to the last proration estimate, some 14,764 acres of "proven producing and non-producing" territory. The northeast flank of the structure has thus far proved to be much more prolific than the opposite side, and involves roughly half the proved acreage. These facts are given for what they may be worth, without venturing any predictions as to yield. At present conditions in the Hendricks pool are so chaotic and uncertain that it would be foolhardy to offer any predictions. It now seems that this field may cover considerably more territory than the Yates. For detailed information on the development in the several fields see the paper by A. R. Denison, page 618.

California

Development in California included several discoveries, notably Alamitos Heights, Rincon (Seacliff), Potrero, and Goleta, as well as several heavy oil districts in the San Joaquin Valley; and perhaps more important in ultimate effect than the new fields, was the development of deeper sands in several older producing districts.

Alamitos Heights, which should be considered an integral part of the Seal Beach field, reached a peak of better than 46,000 bbl. daily late in September and declined rapidly, due to intensive townlot drilling. Rincon, which is a separate high on the Ventura Avenue axis of folding at the point where the structure disappears under the waters of Santa Barbara Channel, has been disappointingly small in the 3200-ft. sand

and unless the deeper pay of the Ventura Avenue field is found, it will be of slight consequence. The Goleta field, producing light gravity oil from the Sespe beds on the north flank of the Ventura Basin yielded only one well of consequence. Additional development demonstrated that structural conditions are very complex, and pointed toward an erratic future. Potrero, which is expected to fill the one obvious gap on the Newport-Beverly line of faulting (between Inglewood and Rosecrans), produced several hundred barrels of light gravity oil from 4700 ft., it is doubtful whether this one well defiinitely marks the discovery of a new field. Despite the great amount of drilling in this area, it is probable that the pool, granting that one exists, has not yet been located. From the foregoing it is evident that the new pools outside the San Joaquin Basin were of slight consequence in swelling the production total for the state.

The several discoveries in the vicinity of Bakerfield and Kern River, although they are in the heavy oil district and therefore not at present in great demand, have a considerable significance for the future. Union Avenue, Fruitvale, Edison—all situated near Bakersfield—serve to indicate that there are possibilities concealed beneath the valley alluvium which have hitherto been unsuspicioned or given slight value. Kern Front, which is yet undefined, has become an important producer, and perhaps gave added confidence to wildcatting in this region. Mount Poso and Round Mountain perhaps indicate the presence of important reserves of oil on a type of structure which is incident to faulting along the granite front of the Sierra Nevada; and they may point to the presence of other as yet undiscovered pools of similar character. Aside from the Kern front, development has not progressed far enough to properly evaluate the importance of these several pools, but in the aggregate they seem to indicate an important reserve of heavy oil for the future.

The deeper drilling in fields of the Los Angeles and Ventura Basins during 1927 serves again to emphasize the vertical dimension of the oil resources of this section. The Long Beach field has launched into a new boom of development to exploit a deeper zone found from 5200 to 6000 ft. This zone was tapped by a few wells several years ago but the fact was not widely advertised and became public property only recently. At the close of the year, some 28 wells had been completed with an average initial capacity of around 1500 bbl. and an unexpected volume of wet gas; and the deep zone will in all probability underlie most of the field. An extensive drilling campaign is now under way and will result in a very important increase in refining crude during the first six months of 1928. Long Beach now affords a zone of productive sands extending from 3000 to 6000 ft. and is perhaps the most phenomenal oil field in the United States from the standpoint of yield, if certain salt dome production of the Gulf Coast is excluded. It should be pointed out also that thus far it is not certain that yet deeper production may ultimately be found.

The deeper zone at Inglewood, which is now proved but held in check by agreement, is an immediately available source of new oil when needed, and it is possible that this may prove more prolific than the zone now producing. Montebello quite likely has a reserve of deeper oil which is at present almost totally undeveloped. Yorba Linda (Richfield) is now responding with prolific production from deeper sands, and Seal Beach has demonstrated the presence of a 6000-ft. pay sand, which however, has so far proved disappointing. There is abundant evidence to lend color to the suspicion that several other pools in the Los Angeles Basin may hold untapped reserves of oil in deeper and untested horizons. Drilling technique and equipment is rapidly improving to make possible a sure exploitation of reserves at greater depths and these fields are probably due for several years to come to furnish new discoveries in deeper sands.

The 7000-ft., 2800-bbl. well in the Ventura Avenue field is especially interesting in this connection. In this unique field it has thus far been possible to increase production whenever necessary by drilling an added depth into the pay zone, but fortunately for the industry, this field is closely held and, as has been demonstrated during the year, it has been feasible to curtail production at will. Incidentally, the pool has several times during the year been extended, and is at present undefined both horizontally and vertically.

In any study of the California situation it is especially important to note Mr. Wagy's estimate that during the year 1927 some 25,000,000 bbl. of oil was withheld from the market by shut-in production. The daily estimated shut-in production in August reached a high point of 93,000 bbl. and was rated at the close of the year at around 75,000 bbl. Most of the oil thus held from the market was of heavy or fuel grade, though at times it included important amounts of refinable grades. On Jan. 1, 1928, it was estimated that some 20,000 bbl. daily of refinable crude was included in the shut-in oil.

Gulf Coast

Geophysical prospecting was vigorously prosecuted throughout the Gulf Coast during the year and netted the discovery of 10 prospective or proved salt domes in Southern Louisiana, and six in Texas. It is next to impossible at any particular time to summarize accurately the results of this work. Competition is keen and as much secrecy is maintained as can be kept from the prying eyes of vigilant scouting departments. Domes discovered by geophysical methods usually result in a unified control of the leasehold, which will result in great benefit to the industry since it will obviate the necessity for reckless and extravagant drilling programs such as have been witnessed in most of the older salt dome fields. On the other hand, it may place a heavy handicap on those interests which fail to secure control of promising new areas. This latter

fact has actively spurred on the competitive scramble for control of new domes. Twelve discoveries were credited to geophysical prospecting in the several years prior to 1927.

The Starks dome in Calcasieu Parish was proved productive early in 1927 and East Hackberry in Cameron Parish yielded two producers later in the year. Sweet Lake, south of Lake Charles, which by the way has not yet been proved a salt dome, furnished production from two wells at 5500 and 5900 ft., respectively. And in February, 1928, a "cap rock" well was brought in on the Sorrento dome, east of the Mississippi River in Ascension Parish. The Sulphur dome, Calcasieu Parish, also yielded its first oil during 1927 although both wells are not now producing. This dome has for many years been a prolific producer of sulfur.

In Texas the Allen dome, Brazoria County, made its first production after a long period of fruitless prospecting. The Orchard dome, Fort Bend County, has had a somewhat similar history. After furnishing a producing well, some 11 dry holes were drilled, before a second producer was located. The last well was finished in the early part of 1928.

It will undoubtedly be several years before the potentialities of these several discoveries are demonstrated. Prospecting around salt domes is a long and expensive undertaking, and dry holes often count for little. In addition to those domes which developed production, certain others were drilled during the year but furnished only negative results. The principal present consideration in the search for salt domes is, that by the location of these additional prospects, the position of the oil industry is greatly strengthened in this section and the future can be viewed with much greater equanimity. Every salt dome is a highly probable source of oil at some time in the future.

East Texas

Salt domes belonging to the so-called "inner belt" have for years been known and prospected throughout East Texas and Northern Louisiana but with negative results. In March, 1927, a well came in from the Woodbine sand on the flank of the Boggy Creek dome in Cherokee County, Texas. It made a heavy production for a brief interval and went to water. This furnished the incentive for an extended campaign of geophysical prospecting during which eight prospective new domes were located. They are situated in the midst of older proved domes and of course cannot be discredited before they are drilled. Almost a year of disappointing drilling around Boggy Creek dome resulted early in 1928 in the completion of a second producing well making better than 100 bbl., and this has served somewhat to revive flagging hopes. Undoubtedly a number of tests are destined to be drilled during coming months around these discoveries but it is fruitless to speculate upon the significance of this situation in the absence of more specific data. In these inner

domes, drilling of the past has demonstrated that the beds punctured by the salt are likely to be tilted at very steep angles. Therefore it appears probable that such production as is discovered will in all probability be confined to a very narrow peripheral belt—that is, granting that the geological characteristics of all these domes conform to those which have been drilled.

Prospects for 1928

Oklahoma production during the current year will probably fall considerably below the 1927 total. West Texas now appears capable of increasing production to more than take care of a decline elsewhere in the state and also make up for any loss in Oklahoma. Whether or not West Texas oil will find its way promptly to market depends solely upon the rapidity with which pipe lines are extended into the area. At this time the pipe line program for coming months has not been announced in sufficient detail to enable one to make predictions as to the rate of movement throughout the year. The present actual production is estimated at 288,500 bbl. daily. California will in all probability produce its usual quota of around 230,000,000 bbl. These three states will as in the past dominate domestic production and one may therefore look forward with considerable assurance to as large production in 1928 as in 1927. This amount of oil can probably be assimilated by an increasing demand and result in far less congestion than has been witnessed in 1927; and it appears probable that cooperation may be depended upon to curb an oversupply much more effectively than in the year just closed. It is safe to assume that West Texas crude will not be stored in any such quantity at its present price level as has been done at Seminole, and therefore unless pipe line transportation is furnished, some means will be found of keeping surplus oil underground.

It now seems probable that the oil industry during 1928 will not permit itself to be the victim of circumstances to anything like the extent that prevailed throughout 1927, and conditions may accordingly be expected to right themselves slowly, so that on the whole the new year may be somewhat more prosperous than the old.

Foreign Production

The foregoing summary deals particularly with the domestic situation but it is apparent that foreign oil must more and more be reckoned with in any forecast of the future. Regardless of its geographic location, any oil produced by foreign interests comes into direct competition with American oil in the markets of the world, and exerts an influence on the welfare of all branches of the industry. Increased supplies of oil from Venezuela, Iraq, Persia, the East Indies, Russia, or any other foreign source, will react in time upon the price of crude and refined products in this country. In the future it will be increasingly necessary for us to

carefully scrutinize the situation in all parts of the world before reaching any conclusion as to the outlook for the American industry.

Venezuelan oil is now in direct competition with Texas crude on the Atlantic seaboard, and even that which goes to Europe will, barrel for barrel, reduce the amount exported to that market from the United States. The amount of oil moved out of Venezuela is dependent upon the capacity of shallow-draught vessels to transport it across the bar at the mouth of Lake Maracaibo. It is estimated that during 1928 the average daily shipments can hardly exceed from 235,000 to 250,000 bbl. for the year, or a total of from 85,000,000 to 90,000,000 bbl. This amount will probably be greatly increased in 1929. Approximately one-half of present production is handled by American companies and finds its way to the American market.

The political situation in Mexico seems to be gradually clearing, but production has taken such a slump that it will undoubtedly require several years for it to resume a position of importance. The older fields are so depleted that only a continued decline can be anticipated, but there are undoubtedly other important fields undiscovered in a country which has been no more extensively wildcatted. A recent 10,000-bbl. well in Mecatepec, some 30 miles south of Tuxpam River, has demonstrated that oil is to be found in other geological horizons than those of the "Golden Lane."

The several shallow wells of the Turkish Petroleum Co. in Iraq, one rated at 92,000 bbl. per day, are probably by far the most important new source of oil developed outside the United States during the year. This oil is produced from the same horizons which have proved so prolific in Persia. Here again there must be a lapse of several years before transportation can be supplied to move the oil to seaboard. Present prospects are that this region will ultimately be a most important source of supply.

Russia, finding that oil is perhaps most readily converted into cash of any of its natural resources, is apparently determined to rehabilitate its oil fields. The past year has witnessed a disastrous price war as the result of marketing Russian oil in the Orient. Further increases in yield are confidently to be expected for several years to come.

It is unnecessary to reiterate here the data presented in the accompanying papers dealing with foreign fields. Enough evidence is at hand to demonstrate rather clearly that the world market cannot possibly be short of oil for several years to come. It therefore seems urgent that American producers lose sight, temporarily at least, of their aggressive competition, and devote themselves to the development of greater teamwork and cooperation in an attempt to ward off a prolonged period of financial disaster.

[The above paper and that by Joseph E. Pogue, on "The Trend of the Petroleum Situation," were discussed together. For the discussion, see page 717.]

Chapter XIII. Domestic Production

Oil and Gas Resources of Kansas in 1927

By L. W. Kesler,* Wichita, Kansas

(New York Meeting, February, 1928)

Kansas produced 41,966,773 bbl. of oil in the year 1927, thereby taking fourth place among the oil-producing states of the Union. The daily average production decreased from 121,609 bbl. in January to 110,244 bbl. in December. Due to excessive flush production and the resulting decline in the price of crude during the year, operations, both in proved and outlying districts, were reduced materially from those of 1926. There were 2338 completions in 1926, but only a total of 1333 in 1927. Regardless of this decrease in the total number of completions, Kansas made a slight gain in total production for the year, producing 620,262 bbl. more than in 1926. This is accounted for, in part, by the comparative long life of the settled production from the Bartlesville sand areas to the east of the Nemaha granite ridge, and by prolific production in eastern Sumner County from horizons new in their importance in the state, productive here at two localities along the axis of the granite ridge. (Table 1 and Figs. 1, 2 and 3.)

Table 1.—*Kansas Production and Completions,* 1920 *to* 1927, *Inclusive*

Year	Total Completions	Total Oil Wells	Total Gas Wells	Total Dry Holes	Dry Holes, Per Cent.	Total New Production, Bbl.	Average Initial Production per Bbl.	Daily Average Production, Bbl.	Total Production, Bbl.
1920	3,164	2,327	147	690	21.8	181,845	78.1	96,848	35,446,427
1921	1,380	909	118	353	25.6	95,789	105.3	97,943	35,749,268
1922	1,640	1,057	86	497	30.3	74,391	70.4	88,733	32,387,646
1923	1,405	807	63	535	38.1	61,372	76.0	81,677	29,812,123
1924	1,125	650	79	396	35.2	92,668	142.5	81,070	29,671,551
1925	2,003	1,281	86	636	31.7	207,880	162.2	104,525	38,151,622
1926	2,338	1,458	96	784	33.5	173,664	119.1	113,278	41,346,511
1927	1,333	685	79	569	42.8	98,253	142.0	114,977	41,966,773

For convenience in further consideration, the state is divided into Eastern and "Western" Kansas. Special emphasis will be placed on those areas in the state of which but little is generally known, and which have not been given detailed consideration in previous publications.

* Resident Geologist, Sinclair Oil & Gas Co.

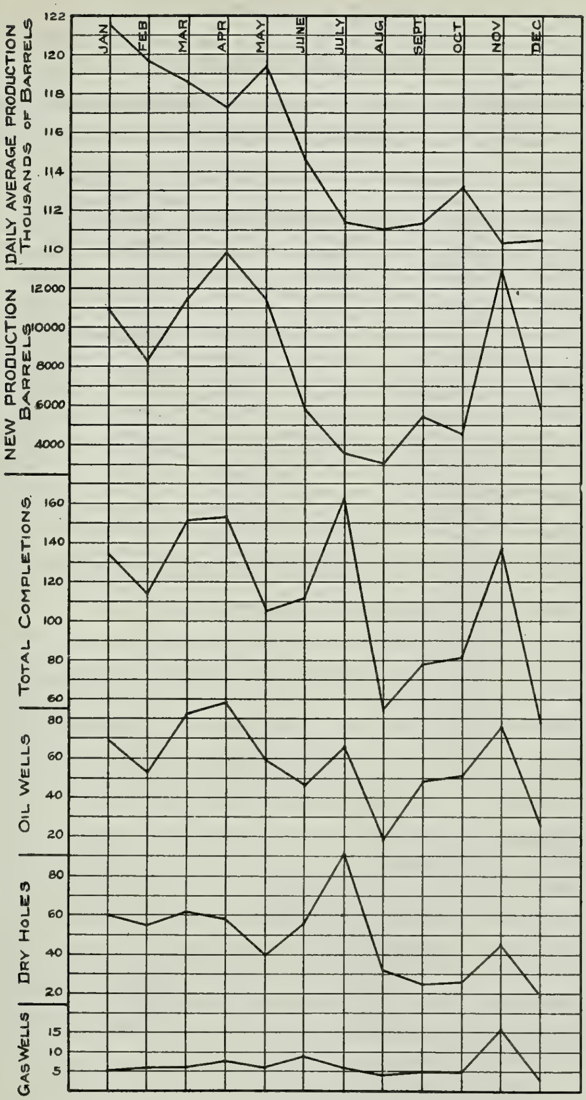
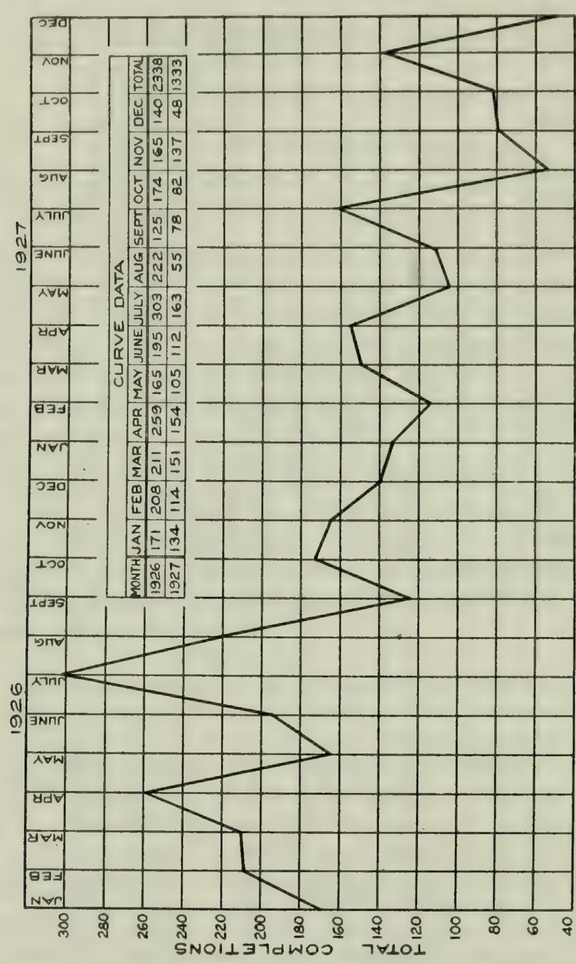


FIG. 1.—DAILY AVERAGE PRODUCTION, NEW PRODUCTION, AND COMPLETIONS IN KANSAS, BY MONTHS, FOR 1927.

Eastern Kansas

The Shoestring Area[1]

Anderson County.—A most important discovery was made in this county in December, 1927. In Sec. 4, -T. 21 S, -R. 21 E, 7 miles east and



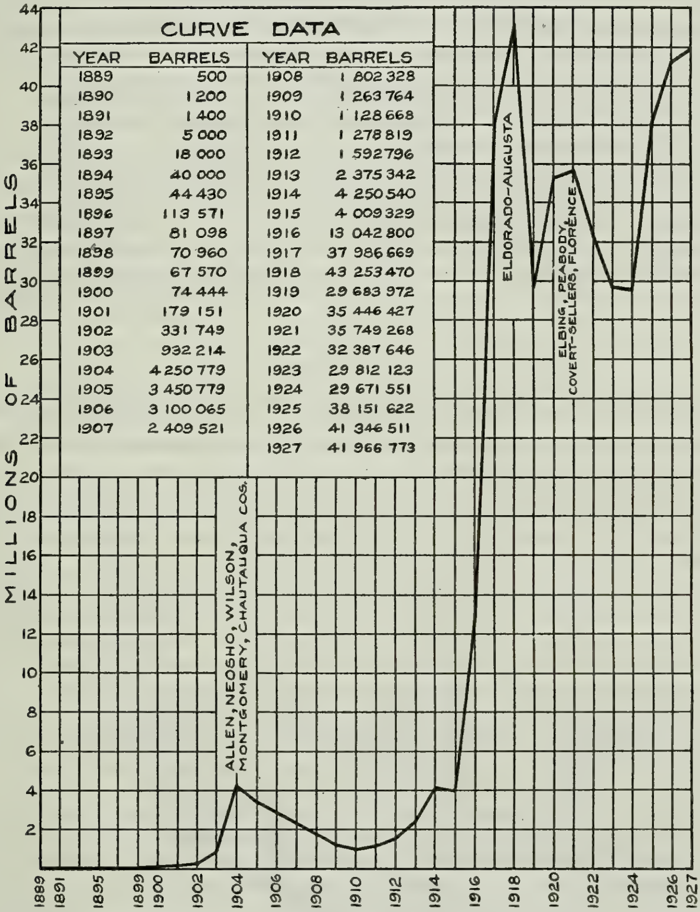
MONTH	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1926	171	208	211	259	165	195	303	222	125	174	165	140	2338
1927	134	114	151	154	105	112	163	55	78	82	137	48	1333

Fig. 2.—Total completions in Kansas, by months, 1926 and 1927.

3 miles south of Garnett, the Schermerhorn Oil Co. completed a Colony sand (Bartlesville) well at a depth of 710 ft., for an initial production of 50 bbl., having a gravity of 34° Bé. This well is significant in that it is

[1] The Shoestring area includes the long and narrow fields in the extreme east-central part of Kansas, typically present in Miami and Anderson counties. They form a complex linear pattern, showing but little definite orientation, and should not be confused with the comparatively straight line Bartlesville sand "trends" of Greenwood and Butler counties.

the first one producing light oil from the Bartlesville sand in Anderson County, although considerable gas is produced from that horizon. In fact, heretofore, there have been no Bartlesville oil pools in the shoestring area north of the south line of Twp. 25 S. Early in 1928, seven wells were completed and drilling was most active.[2]



YEAR	BARRELS	YEAR	BARRELS
1889	500	1908	1 802 328
1890	1 200	1909	1 263 764
1891	1 400	1910	1 128 668
1892	5 000	1911	1 278 819
1893	18 000	1912	1 592 796
1894	40 000	1913	2 375 342
1895	44 430	1914	4 250 540
1896	113 571	1915	4 009 329
1897	81 098	1916	13 042 800
1898	70 960	1917	37 986 669
1899	67 570	1918	43 253 470
1900	74 444	1919	29 683 972
1901	179 151	1920	35 446 427
1902	331 749	1921	35 749 268
1903	932 214	1922	32 387 646
1904	4 250 779	1923	29 812 123
1905	3 450 779	1924	29 671 551
1906	3 100 065	1925	38 151 622
1907	2 409 521	1926	41 346 511
		1927	41 966 773

FIG. 3.—ANNUAL PRODUCTION IN KANSAS, 1889 TO 1927, INCLUSIVE.
Based on production figures taken from *Oil and Gas Journal*, and from University Geological Survey of Kansas, "Mineral Resources of Kansas, 1903," by Erasmus Howarth, State Geologist (1904).

A brief review of Anderson County development follows: The most important fields are the Garnett oil shoestring, averaging two locations in width, and extending from Sec. 31, -T. 20 S, -R. 20 E, to Sec. 2, -T. 21 S, -R. 19 E; the Colony-Welda gas shoestring, about ½ mile wide and 13 miles long, extending from Sec. 20, -T. 21 S, -R. 19 E, to Sec. 12, -T.

[2] John L. Rich: Personal Communication, Feb. 17, 1928.

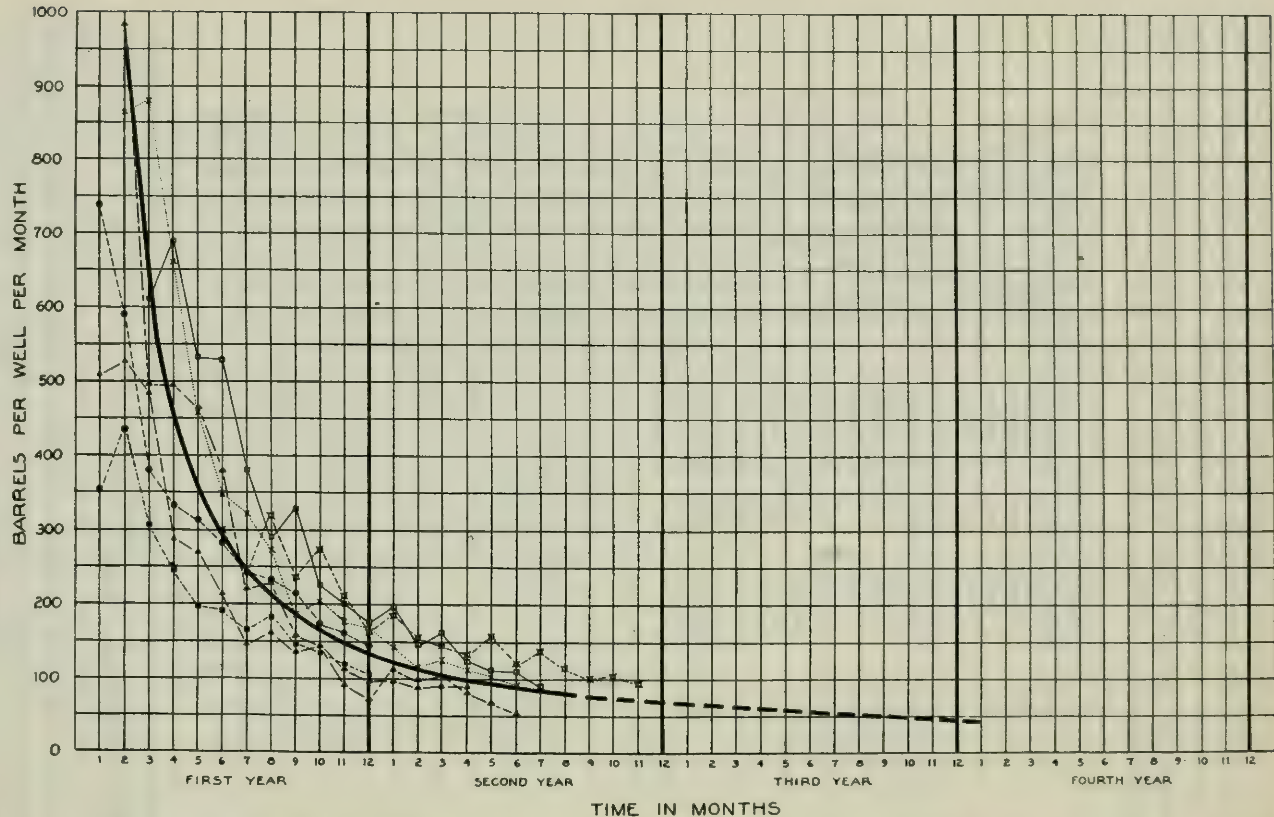


FIG. 4.—PRODUCTION DECLINE CURVE OF BUSH CITY SHOESTRING OIL FIELD, ANDERSON COUNTY, KANSAS. THIS IS A REPRESENTATIVE DECLINE CURVE OF CHANNEL DEPOSIT FIELDS OF THAT DISTRICT.

Taken from "Oil and Gas Resources of Anderson County, Kansas," by Homer H. Charles. State Geological Survey of Kansas, *Bull.* 6, Pt. 7, Lawrence, Kan. (1927).

23 S, -R. 18 E; and the Bush City oil shoestring averaging ¼ mile wide and developed for 13 miles in length from Sec. 14, -T. 21 S, -R. 19 E to Sec. 27, -T. 20 S, -R. 21 E.

The latter is one of the best representatives of the shoestring type of pool in eastern Kansas. From March, 1923, to January, 1926, 775 oil wells, with an initial production each of from 5 to 800 bbl., were completed in this pool. The depth of the wells is from 650 to 850 ft. The gravity of the oil is 36° Bé. The average initial production was 60 bbl., declining to 5 bbl. at the end of 1 year, 2 bbl. at the end of 2 years, and 1¼ bbl. at the end of a 3-year period. The wells located in the synclinal parts of the shoestring made initially 5 to 50 bbl. each, while those in the anticlinal areas came in for 50 to 250 bbl. The average recovery per acre by natural methods may be expected to reach a total of approximately 2500 barrels.[3]

A representative decline curve of the Bush City shoestring, typical of the channel deposit fields of that district of eastern Kansas, is shown in Fig. 4.

Butler County

Butler County produced 25.1 per cent. of the gross production of the state in 1927.

The principle producing horizons are the Bartlesville sand "trends," of Pennsylvanian age (Cherokee); and the Viola lime,[4] "Wilcox" sand, and "Siliceous lime" of Ordovician age. The Pennsylvanian and Ordovician horizons produce about an equal quantity of oil, and together, approximately 97 per cent. of the total. New discoveries and development in Butler County during 1927, follow:

Marnane Pool (Benton).—In February, 1927, the Barnsdall Oil Co. completed No. 1 Marnane, located in the NE corner NW ¼ SW ¼ of Sec. 20, -T. 26 S, -R. 3 E, for an initial production of 110 bbl., testing 40° Bé. The producing horizon is in the upper part of the Mississippi lime, found at a depth of 2850 ft. One other oil well was completed at this horizon for 30 bbl. initial production. Two additional tests were failures, one of which was deepened to the "Wilcox" sand, and the "Siliceous lime."

The accumulation here was probably due to an indistinct structural terrace.

Haverhill Field.—In April, 1927, the Empire Oil & Refining Co. completed 2 producers, 1 mile apart, No. 1 Hutchinson located in the SW corner NE ¼ of Sec. 34, -T. 27 S, -R. 5 E, and No. 1-A Hutchinson located in the SE corner SW ¼ NE ¼ of Sec. 27, -T. 27 S, -R. 5 E. These two wells came in for an initial production of 100 bbl. each, testing 40° Bé., from the Bartlesville sand found at an approximate depth of 2700 feet.

[3] Homer H. Charles: Anderson County. See Oil and Gas Resources of Kansas, State Geol. Surv. of Kans., *Bull.* 6 (1927) Pt. 7, 72.

[4] Refer to discussion of the Leon district, following.

Three offsets to the south well and two offsets to the north well have been completed for an average initial production of 50 bbl. At the end of 1927, the seven wells were averaging 20 bbl. each, daily. It is highly probable that another sand "trend" is in the process of development.[5]

Leon District.—In Township 27 S, Range 6 E, and Township 28 S, Range 6 E, Butler County, a steady development has continued through 1927 as a result of scattered discovery wells, some of which were complete in 1926. This locality has brought forth an important producing horizon but little discussed and not definitely determined in Kansas until recently, namely, the Viola lime (Urschel lime of Barwick). Being unexpected and located near the town of Leon, it was immediately called the "Leon" lime. With subsequent development and detailed study, it has become possible to correlate it definitely with at least part of the Viola of Oklahoma, and this nomenclature (Viola or Urschel) should take precedence over the term "Leon."[6]

Eldorado.—In the Eldorado pool, during 1927, approximately 100 wells were completed in the "650-foot" sand for an average initial production of 5 bbl., having a gravity of 36° Bé.

Seward-Keighley "Trend."—Considerable attention has been directed during 1927 toward the continuance of the Seward-Keighley "trend" (Twp. 27 S, -R. 7 E) in a southwesterly direction, but thus far with no success. It is probable, and with good reason, that further attention will be given this area during 1928.

Greenwood County

In 1927, Greenwood County produced 27.8 per cent. of the gross production of the state. The Bartlesville sand is the source of nearly all the production in the county. A comparatively small amount is secured from the Mississippi lime, but other producing horizons are negligible. The average gravity of the oil is 40° Bé.

Development and new discoveries for 1927, follow:

Eureka Pool Development.—The Eureka pool, located in Sections 2 and 3, -T. 26 S, -R. 10 E, and Sections 33 and 34, -T. 25 S, -R. 10 E, was discovered some years ago, but in the early part of the summer of 1927, production was extended into the town proper. Townlot drilling began about in June and at the close of the year, 18 oil wells had been completed on the townsite for a total initial production of 885 bbl. or an average per well of 49 bbl. Six tests were dry holes. The producing horizon is the

---

[5] Early in 1928, the Empire Oil & Refining Co. completed a well in the SE corner NW ¼ SE ¼ of Sec. 22, -T. 27 S, -R. 5 E, ¾ mile due north of Hutchinson No. 1-A, for an initial production of 500 bbl. from the Bartlesville sand. This discovery is further evidence of a north-south sand "trend."

[6] John Reeves: Personal Communication.

John S. Barwick: The Salina Basin of North-Central Kansas. *Bull.* Amer. Assoc. Petrol. Geol. (1928) **12**, No. 2, 184.

top of the Mississippi lime found at about 1900 ft. Accumulation here is controlled by structure, a part of the Beaumont Anticline.

Climax Pool Development.—Production from the top of the Mississippi lime was discovered some time ago at a depth of 1850 ft. in Sections 4 and 9, -T. 27 S, -R. 11 E. In 1927, three oil wells with an average initial production of 100 bbl. each, and one dry hole, were completed. The gravity of the oil is 32° Bé.

DeMalorie-Souder Extension.—In 1927, 1 mile west of the DeMalorie-Souder prolific field, an important extension was opened up in the SE corner of Sec. 3, -T. 22 S, -R. 10 E, by Bruce and Bradley and the Skelly Oil Co. Four wells have been completed in the Bartlesville sand, found at a depth of 2150 ft., for a total initial production of 735 bbl., or an average per well of 184 bbl. The gravity of the oil is 41° Be. This important "trend" extension will be the cause of considerable development during 1928.

Madison Extension.—In January, 1927, the Roxana Petroleum Corpn. with Schwartz and McDougal, extended production 1 mile to the southeast by the completion of a Bartlesville sand well at 1800 ft. in the NE corner NW ¼ NE ¼ of Sec. 23, -T. 22 S. -R. 11 E. Ten wells were completed within the year having a total initial production of 1570 bbl., or an average per well of 157 bbl. The gravity is 41° Bé. This is another extension of Bartlesville sand "trend" production in Greenwood County which offers much possibility and will receive considerable attention in 1928.

Quincy Pool.—The Quincy pool, located in Sections 10 and 15, -T. 25 S, -R. 13 E, was discovered in November, 1927. Four wells in all were completed during the year for a total initial production of 520 bbl., or an average of 130 bbl. per well. The oil, testing 39° Bé., comes from a Bartlesville sand "trend," found at a depth of 1450 ft. Gas, up to the amount of 750,000 cu. ft., is produced with the oil. The discovery is of great importance because of its position as a possible connecting link for other "trends."

Edwards Pool.—In March, 1927, the Empire Oil & Refining Co. opened up an extension to the Seeley pool, 1 mile southeast of the latter, in Sections 16, 17 and 21, -T. 23 S, -R. 11 E. Seventeen oil wells were completed in the Bartlesville sand at a depth of 1900 ft., for a total initial production of 3038 bbl., or an average of 178 bbl. per well. The oil tests 40° Bé. This is "trend" production, a part of the "cross-trend" which includes the Seeley and DeMalorie-Souder pools. The extension is still open to the southeast and considerable development may be expected in 1928.

Lamont Pool.—The most prolific discovery in Greenwood County in 1927 was that of the Lamont pool. The discovery well, Demler No. 1, located in the NW corner NE ¼, Sec. 25, -T. 22 S, -R. 12 E, was

completed in June by the Empire Oil & Refining Co. at a depth of 1600 ft. for an initial production of 500 bbl. testing 40° Bé. Thirty-one oil wells and seven dry holes had been completed at the close of the year. The total initial production was 9845 bbl., or an average of 318 bbl. per well. The maximum initial production for a single well was 950 bbl. A townsite (Lamont) drilling campaign resulted in five of the dry holes and seven of the oil wells on about 40 acres. In December, the proved production area of the pool was over 1 mile long and ½ mile wide, and its daily average production was approximately 3500 bbl. At the close of the year the two ends of the pool were still open and development was continuing rapidly in both directions.

This "strike" was the most important one in eastern Kansas during 1927, and may develop into one of the best Bartlesville sand "trend" pools in Greenwood County.

Cowley County

No new pools were discovered in Cowley County in 1927. In January there were 353 producing oil wells in the county, and in December this number had increased to 402. The total production for the year was 3,097,502 bbl. (not including miscellaneous), divided as follows:

	Barrels
Winfield	1,206,588
Rainbow bend	802,672
Slick-Carson	419,333
Eastman	264,252
Graham	229,196
Rock	96,484
Clark	78,977
Miscellaneous (not included)	

A brief review of each of the fields to the close of 1927, follows:

Rainbow Bend Pool.—The discovery well of the Rainbow Bend pool was completed Dec. 19, 1923, in the NW corner SE ¼ of Sec. 20, -T. 33 S, -R. 3 E, Cowley County, Kansas, by Waite Phillips Co. At the close of 1927, 125 producing wells had been completed in the field proper, and 12 producers in the extension 1 mile west in Sec. 19, -T. 33 S, -R. 3 E, and Sec. 24, -T. 33 S, -R. 2 E. On March 12, 1927, a producing well was completed by the Barnsdall Oil Co. in the NW corner SW ¼ of Sec. 8, -T. 33 S, -R. 3 E, 1½ miles north of the field. At the peak of production, reached in June, 1926, the field produced approximately 22,500 bbl. daily. At this time 112,000,000 cu. ft. of gas was produced with the oil. The gravity is 39° to 41° Bé.

In the major part of the field, production is secured from a sand in the basal part of the Cherokee shale resting on the Mississippi lime, and found at a depth of 3200 to 3250 ft. In the west extension, production

is from a similar sand at the same horizon and also from the top of the Ordovician "Siliceous lime" found near 3550 ft. In Sections 7 and 8, -T. 33 S, -R. 3 E, production is found in the "Siliceous lime" at a depth of 3500 feet.

Graham Pool.—The discovery well in this pool was completed July 1, 1924, in the NE corner of Sec. 9, -T. 33 S, -R. 3 E, Cowley County, by the Marland Refining Co. During the development of this field, 35 producing wells were drilled in the east half of Sec. 9 and the west half of Sec. 10, -T. 33 S, -R. 3 E. Production is obtained from two horizons, the Layton sand and the "Siliceous lime." The former, often termed the "shallow pay," is found at a depth of 2550 ft., a short distance above the limestone portion of the Kansas City formation. The "Siliceous lime" is the more prolific horizon, and is encountered at 3500 ft. The gravity of the oil from the Layton sand is 38.5° Bé., and of that produced from the "Siliceous lime," 39° to 40° Bé. The Ordovician oil has the characteristic hydrogen sulfide odor.

Slick-Carson Field.—The discovery well of the Slick-Carson field was completed Oct. 29, 1924, in the SW corner NE ¼ of Sec. 19, -T. 32 S, -R. 3 E, Cowley County, by T. B. Slick. Twenty-six producing wells have been drilled in this field. Production here is from three horizons. The uppermost is a sand (or sandy phase) in the top of the Kansas City lime which is probably equivalent to the Layton sand farther south, and found here at an approximate depth of 2600 ft. There are 12 wells producing from this horizon. The next lower is a sand near the base of the Cherokee shale from which two wells are productive at a depth of 3100 ft. The most productive horizon is the "Siliceous lime" found at a depth of 3425 ft. and from which 12 wells produced. The oil from this field tests 38° to 40° Bé., the gravity rising with the increased depth of the producing horizon.

Winfield Pool.—In 1927 the Winfield pool produced more than half of the total production of Cowley County. The discovery well, located in the NW corner SE ¼ of Sec. 36, -T. 32 S, -R. 4 E, was drilled by the Empire Oil & Refining Co. during the latter part of 1914. This production was found in sand at the shallow depth of 1450 ft. in the upper part of the Lawrence shale of the Douglas formation. Soon after the completion of this well, A. L. Derby and others secured a producer at this horizon in the NE ¼ of the same section. Following this, 20 additional producing wells were completed. The horizon was productive over a small area only. A short time after these wells were drilled, the Arkansas Fuel Co. completed a small producer in the NW ¼ of Sec. 7, -T. 32 S, -R. 5 E, in the 2400-ft. sand. On May 11, 1922, the Emerald Oil Co. and McKnabb obtained production from the 1400-ft. sand in the NW corner SE ¼ of Sec. 24, -T. 32 S, -R. 4 E, in an area which has been proved by later operations to be the major part of the field.

Further development has extended the production in a discontinuous series of small pools through Sec. 13 and the SE ¼ of Sec. 12, -T. 32 S, -R. 4 E, and the W ½ of Sec. 7 and northward into Sec. 6, -T. 32 S, -R. 5 E. This discontinuous strip of production 6 miles long, follows in a general way the axis of the Winfield closed anticline from which the production is obtained.

On June 29, 1926, the J. A. Hull Co. completed an important addition to this area in the NW corner SE ¼ of Sec. 15, -T. 32 S, -R. 4 E, by the discovery of oil in the "Siliceous lime" at 3304 ft. on the State Home land. This horizon proved to be very prolific here, but only over a small area. Oil is also produced from the Layton sand, and gas from a sand a little above this horizon.

Several shows of oil have been recorded in the lenticular sand in the Weston shale at approximately 1750 ft. Also numerous shows have been recorded in the sands or sandy limes in the top of the Lansing formation, but no commercial production has been obtained here. This horizon is present at a depth of approximately 1900 feet.

A few small wells have produced from a sand or sandy limestone occurring in Sec. 24, -T. 32 S, -R. 4 E at an approximate depth of 2100 ft., possibly equivalent to the Plattsburgh limestone of the Lansing formation.

The most productive shallow horizon is known as the "2300-foot" sand which, in this locality, is a sandy phase of the top of the Kansas City formation, probably equivalent to the Layton farther south.

There are one or two other thin discontinuous sandy phases near the base of the Kansas City formation, and in the Marmaton below, in which frequent shows are recorded and from which a minor amount of production is obtained.

The most productive horizon in the Winfield pool is a sand found at 2950 to 3000 ft. in the basal Cherokee shale, which in most instances rests unconformably on the Mississippi lime, but it is separated from the latter in some of the wells by several feet of shale.

The gravity of the oil found in this area ranges from 37.5° to 40.5° Bé. Some of the Pennsylvanian producing horizons here are often productive in one or two wells, but dry in the offsets.

Clark and Shaffer Pools.—The discovery well of the Clark pool was drilled in the NE corner SE ¼ NW ¼ of Sec. 6, -T. 31 S, -R. 4 E, Cowley County, in 1916, by the Little Pirate Oil Co. Production was limited to four wells, three of which were still producing at the close of 1927. The discovery well of the Shaffer pool was completed in the SE corner NE ¼ of Sec. 10, -T. 31 S, -R. 3 E on Nov. 19, 1924, by the Trees Oil Co. The development here consisted of 10 oil wells. In both pools, the producing horizon is a sand in the basal Cherokee shale, 30 to 40 ft. above the top of the Mississippi lime and found at 2850 ft. in the Clark pool and at 3050 ft.

in the Shaffer. A very small amount of gas is present with the oil. The gravity varies from 37.5° to 38.5° Bé.

Rock Pool.—The discovery well of the Rock pool was completed Jan. 13, 1923, in the NE corner of Sec. 15, -T. 30 S, -R. 4 E, Cowley County, by the Cassoday Oil Co. Since that time 20 producing wells have been completed in the NE ¼ of Sec. 15 and in the nearby parts of adjacent sections. The production comes from a sand in the Cherokee shale approximately 75 ft. above the top of the Mississippi lime, and found at an average depth of 2775 ft. The oil tests 38° Bé.

Eastman Pool.—The discovery well of the Eastman pool was completed in the SW corner of Sec. 5, -T. 31 S, -R. 6 E, Cowley County, Feb. 18, 1924, by the Southwestern Petroleum Co. At the close of 1927, 48 oil wells and 5 or 6 gas wells had been completed in the western half of Sec. 5 and the eastern half of Sec. 6, -T. 31 S, -R. 6 E, and in Sec. 31, -T. 30 S, -R. 6 E. The production is obtained from a sand in the basal part of the Cherokee shale, 5 to 50 ft. above the Mississippi lime, and found at a depth of 2800 to 2850 ft. The oil tests 38° Bé., gravity.

Miscellaneous.—At the close of the year 1927 there were 43 oil wells widely distributed in various parts of Cowley County outside of the above areas, producing a total of 657 bbl. daily. A number of them have been producing for several years, but none, including those completed recently, are expected to open up extensive productive areas.

Sumner County (*Ranges East*)

This is the banner county for new production in Kansas in 1927. As a unit in the compilation of production figures, it heads the list; as a county it ranks third, producing 6,708,275 bbl., 15.98 per cent. of the total production of the state. Two prolific pools, the Churchill and Oxford, are responsible for this splendid showing. Both were discovered following core drill operations and are signal examples of the benefits to be derived from such procedure.

A brief summary of the pools follows:

Churchill Pool.—This pool was the most important discovery in Kansas during 1926, and was the first production of any consequence on a granite ridge structure south of Township 29 S, -Range 4 E, Butler County. The discovery well, located in the NE corner SW ¼ of Sec. 25, -T. 31 S, -R. 2 E was completed July 2, 1926, by the Roxana Petroleum Corpn. During the remaining six months of that year 18 oil wells were completed, and in 1927, 44 additional producers brought the total to 62. The peak of both development and production was reached during the first half of 1927. In December of that year a dozen or more proved locations remained to be drilled. The actual productive area at the

close of the year, included approximately 700 acres in Sections 24, 25, 26 and 36, -T. 31 S, -R. 2 E.

Production is secured from the Stalnaker sand, found at a depth of from 1860 to 1900 ft., and usually marked by a lime shell at the top. The sand thickness on the structure exceeds 100 ft., and part of it contains numerous shaley phases. The gravity of the oil is 38° Bé. Possibilities of deeper producing horizons exist, but no operations, well located on top of the structure, have thus far been drilled to them. Very little gas occurs with the oil, and partly for this reason, air-lifting apparatus has been installed. This is the first field in Kansas to be produced by this method from the time of its discovery. Insufficient data are at hand for the purpose of estimating the ultimate recovery per acre, but it will undoubtedly be highly satisfactory.

Oxford Pool.—The discovery well of the Oxford pool was completed on the townsite of Oxford, 1000 ft. north and 615 ft. east of the center of Sec. 14, -T. 32 S, -R. 2 E, Sumner County, early in May, 1927. At the close of the year there were 27 producing wells and a number of others drilling. Production, apparently defined on the north and east, had extended from the SW 1/4 SW 1/4 of Sec. 12, -T. 32 S, -R. 2 E, in a southwesterly direction to the NE 1/4 NW 1/4 of Sec. 23, -T. 32 S, -R. 2 E, a distance of a mile and a half. The southern limits of the field are near at hand, and the average width will not exceed a half mile.

By far the most important of the producing horizons is the Stalnaker sand found at a depth of from 1950 to 2025 ft. This, which is also the productive sand in the Churchill field, 4 miles to the northeast, is marked at the top by a thin lime or sandy lime shell. It contains a considerable but variable amount of interbedded shale partings or sandy shale. The thickness of the sand on top of the structure is not known, no well having passed through it, but only a short distance down the flank of the structure, 150 ft. has been found. Two wells in the field have drilled 120 and 130 ft. of sand without penetrating its entire thickness.

There are two horizons above the Stalnaker which are commercially productive and several more in which shows of oil have been obtained. Six wells are producing from one of these, a sandy limestone found at an average depth of 1260 to 1275 ft. This horizon, apparently by common consent, has been called the top of the Topeka lime, but there is good evidence for the belief that it is approximately 110 ft. higher in the section, but still of Shawnee age. One well, located in Block 88, townsite, produced considerable oil from a sandy limestone found at a depth of 1065 ft. This is probably in the lower part of the Waubaunsee formation. A few wells have had commercial shows of oil at 1600 and 1775 ft. in horizons as yet unidentified.

Similar to the Churchill pool, the gravity tests 38° Bé., and recovery is assisted by air-lift.

Miscellaneous.—In 1927, nine other oil wells were producing in the eastern part of Sumner County. Five of these (the Miller pool) are located around the center of Sec. 17, -T. 32 S, -R. 2 E, and produce from the Ordovician "Siliceous lime" at a depth of 3650 ft. This oil tests 38° Bé. The discovery well was completed by the Roxana Petroleum Corpn. June 2, 1926.

Marion and Chase Counties

Reznicek Pool.—In November, 1926, near the town of Lost Springs in Marion County, Frank, with Harwood and Winters, completed No. 1 Reznicek, located in the SW ¼ NW ¼ of Sec. 22, -T. 17 S, -R. 4 E, in the "chat" of the Mississippi lime, for an initial production of 75 bbl., testing 37.5° Bé. In the spring of 1927 this well was deepened 30 ft., resulting in a new initial production of 275 bbl. By June, 1927, three offset wells had been completed for an average initial production of 850 bbl. per well. The four were shut in to 50 bbl. each per day for the remainder of the year. The total production for 1927 (with wells shut in), amounted to 73,947 barrels.

Lost Springs Townsite Pool.—In the latter part of December, 1927, Loriaux and Robinson completed an oil well on the Lost Springs townsite, in Sec. 23, -T. 17 S, -R. 4 E, for an initial production of 200 bbl., also producing from the Mississippi lime "chat" horizon.[7]

Propp Gas Field.—In April, 1926, a gas well was completed in Sec. 8, -T. 19 S, -R.4 E, Marion County, by Frank and Propp et al., having an open flow of 4,000,000 cu. ft. and a rock pressure of 845 lb. The gas horizon is the Mississippi lime "chat," found at a depth of 2367 ft. Two additional wells were completed, but for a much less volume and a rock pressure of about 700 lb. One well was first completed for 15 bbl. of oil at a depth of 2398 ft., 43 ft. below the top of the "chat," but this was plugged back later and recompleted as a gas well of 1,250,000 cu. ft. capacity.

Lipps Gas Area.—This area, located in Sections 25, 36, -T. 18 S, -R. 6 E, and Sections 29, 30, 31, 32, -T. 18 S, -R. 7 E. Chase County, was discovered by Preston and Pasewalk late in 1925, but did not attain its peak until the spring and summer of 1927. At the close of the year, 18 gas wells and 9 dry holes had been completed. Four other wells were abandoned because of difficulties. The average initial volume per well was 2,750,000 cu. ft., with a rock pressure of 475 to 480 pounds.

The producing horizon is a true sand with an average thickness of 22 ft., in the Lawrence shale, but 120 ft. below the top of the Oread

[7] Early in 1928, many operations are under way and locations extend all the way from the Reznicek pool to the Townsite discovery well. The Reznicek pool "shut in" agreement has been lifted.

lime and 160 ft. above the top of the Lansing formation. The field is located on or very close to the principle axis of the Nemaha granite ridge.

"Western" Kansas

"Western" Kansas has received but little attention by way of the publication of knowledge, relative to production or to scientific determinations, gained as a result of the discovery of oil within its limits, and the subsequent intensive search for additional reservoirs. Local areas have been treated fully, and a number of "geologic notes," their contents of prime value, have been set forth.

Information submitted in this paper, however, covers the entire area, Townships 1 to 35 South, Ranges 1 to 43 West, inclusive, with special reference to the development of oil and gas, and to the more important, somewhat basic principles of geologic interest directly associated with it.

The area comprises two-thirds of the state (about 54,180 sq. miles), and has produced approximately 5,442,986 bbl. of oil, 33 per cent. of this during 1927. Therefore, its potentialities should receive much more consideration.

General Statement

This relatively large area may be divided into three, broadly generalized areas, on the basis of its pre-Pennsylvanian stratigraphy:

1. A relatively small area comprising the northeastern and east-central part of "western" Kansas, wherein a great thickness of Mississippian and Siluro-Devonian sediments separate the Pennsylvanian from the Ordovician. In this area the Ordovician post-"Siliceous lime" sediments attain a remarkable thickness which increases progressively northward.

2. An area of considerable extent lying, in general, south of the Arkansas River from Range 1 W to Range 43 W, inclusive, but probably extending an undetermined distance north of the river west of Kinsley, wherein both thick and thin Mississippian but thin, or totally absent, Siluro-Devonian sediments separate Pennsylvanian from Ordovician. Here, the Ordovician post-"Siliceous lime" sediments are relatively thin.

3. A vast area, comprising all of northcentral-"western" Kansas, together with an undetermined extent in northwestern-"western" Kansas, wherein Pennsylvanian strata rests directly upon sediments of Ordovician or Pre-Cambrian age. Further subdivisions and refinements of the above areas can naturally be made, but this in general describes the character and distribution of the sediments which formed the floor over which the Pennsylvanian sea advanced.

The oil fields in "western" Kansas, with the exception of two, have all been developed within Area No. 3. This by no means precludes the oil possibilities of the remaining two areas. Their chief potential producing horizon lies at a considerably greater depth and, therefore, exploitation has been slower. In addition, many of the wells which started to this horizon, stopped, unfortunately, from 100 to 400 ft. short of their objective.

Some years ago the oil horizons under most of "western" Kansas were thought to be far below reach of the drill. This conclusion was based, in part, on the opinion that a normal eastern Kansas section existed below the Pennsylvanian. Today it is known that within Area No. 3, all of the Mississippian and Siluro-Devonian sediments have been removed. Furthermore, due to a regional dip of the Ordovician to the southeast, the latter rises westward nearer and nearer to the surface, and progressively more and more of the lower Pennsylvanian is cut out. Some idea of this convergence between Permian and Ordovician (the maximum convergence is in a northwest-southeast direction), may be gained from the fact that in a distance of 260 miles some 4420 ft. of sediments are cut out between the base of the Cimarron Group (Permian) and the Ordovician. This is at the rate of 16 ft. per mile.

Within Area No. 3, where Pennsylvanian rests directly on Ordovician or older sediments: 11 wells have been drilled into the Pennsylvanian basal conglomerate; 65 wells have been drilled into the Ordovician; 12 wells have encountered crystalline rocks after penetrating through the Ordovician; 3 wells have passed directly from Pennsylvanian into crystalline rocks.

The extreme western limit in "western" Kansas, where Ordovician or older rocks have actually been penetrated, lies in Township 2 S, -Range 26 W, Decatur County. A thick pre-Pennsylvanian section of undetermined age has been drilled in Township 32 S, -Range 21 W, Clark County. And in Township 26 S, -Range 41 W, Hamilton County, a well has been drilled to a depth of 5488 ft. which possibly encountered rocks of Mississippian age near the bottom of the hole.

The greater number of wells which have penetrated directly from Pennsylvanian into Ordovician, lie east of Range 25 W.

In 1927, six wells in "western" Kansas penetrated into arkosic, granitic, or metamorphic rocks. All of these went directly out of Pennsylvanian into Ordovician. The most interesting of them is that of Hoffine and Crane, No. 1 Bock. Here, the top of the Pre-Cambrian metamorphic rocks was encountered at approximately 3810 ft., and drilling was continued for 1280 ft. in them (probably mostly schist) without, so far as known, reaching granite.

Development

A total of 517 wells, drilled for oil and gas, have been completed in "western" Kansas (Ranges 1 to 43 West) to the close of 1927. Of this number, 145 have produced oil, and 11 gas, making a total of 156 producing wells, or 30 per cent. of the total number drilled.

Out of the 62 counties which comprise "western" Kansas, exploitation for oil and gas has been pursued in 48. About 82 per cent. of the wells drilled have been confined to 14 counties in which the intensity of development ranks as follow:

	Completions		Completions
1. Russell County	152	8. Barton County	15
2. Sumner County (Ranges West)	46	9. Barber County	15
3. Rice County	45	10. Ellsworth County	13
4. Kingman County	26	11. Lincoln County	12
5. Reno County	26	12. Harper County	12
6. McPherson County	26	13. Ellis County	10
7. Sedgwick County (Ranges West)	19	14. Rooks County	10
Total			427

Prior to 1927 the bulk of the prospecting in "western" Kansas (exclusive of the Fairport field) took place in 1924 and 1926. A renewal of interest and activity during 1927 resulted in the completion of 114 wells, or 22 per cent. of the total number which have been drilled. Seventy-five per cent. of these were wildcat tests. Thirty were completed as oil wells and six as gas wells.

One of the salient facts, from a scientific standpoint, about 1927, is that practically all of the wells penetrated to a sufficient depth to increase materially a knowledge of the subsurface stratigraphy of "western" Kansas. A critical study of the 114 completions shows the depth to which these wells were drilled:

Number of Wells	Depth, Ft.
2	1000 to 2000
6	2000 to 3000
65	3000 to 4000
40	4000 to 5000
1	5000 to 6000

The following table indicates the stratigraphic horizon to which wells were drilled during 1927:

0 Stopped in Cretaceous	
4 Stopped in Permian	3 Drilled into Cimarron group. 1 Drilled into Big Blue group.
25 Stopped in Pennsylvanian	24 Drilled into Missouri group. 1 Drilled into Des Moines group.
32 Stopped in Mississippian	24 Drilled into Mississippi lime. 8 Drilled into Kinderhook group.
2 Stopped in the Siluro-Devonian	

45 Stopped in the Ordovician	25 Penetrated Ordovician after drilling through a normal section of Mississippian and Siluro-Devonian.
	20 Passed directly out of Pennsylvanian into Ordovician.

6 Stopped in granitic, arkosic, or metamorphic rocks.

Producing Areas and Producing Horizons

There are eight actively producing oil areas in "western" Kansas and two actively producing gas areas. In addition to these, there is one abandoned oil-producing area, one potential oil-producing area, and four potential gas-producing areas. The producing areas appear in Table 2 and the oil horizons of the Fairport field, Russell County, in Table 3. The age of the producing horizons in descending order, and the number of wells producing from each, follow:

Producing Horizons	Number Producing Wells
1. An unidentified horizon in the lower part of the lower Permian	4
2. A gas horizon in the Topeka lime (Shawnee formation); Middle Pennsylvanian	2
3. "Oswald Series"—9 producing horizons in a 320-ft. thickness of strata between the top of the Oswald lime and the base of the Pennsylvanian basal conglomerate: all of middle Pennsylvanian	113
4. Layton Sand (Kansas City formation); Pennsylvanian	2
5. Basal Kansas City formation: Pennsylvanian	1
6. Mississippi lime	33
7. Wilcox; Ordovician	1

Innumerable shows of oil have been encountered in the top of the Lansing formation, in the top of the Mississippi lime, and in the Viola lime. Occasional shows of oil and gas have also been found in the Permian, and in the Wabaunsee and Shawnee formations of the upper Pennsylvanian.

Interesting and Important Wells Completed during 1927

Sumner County.—Unquestionably the most important well completed during 1927, offering potential production and the possibility of a new field, was that of the Gypsy Oil Co. No. 1 Douglas, NE corner SE ¼ NW ¼ of Sec. 23, -T. 34 S, -R. 2 W. In July, 1927, this well encountered the top of the "Wilcox" sand at 4490 ft., and drilled 10 ft. into it to the total depth of 4500 ft. (base not reached). From 4492 to 4500 ft., the well made an initial production of 480 bbl., testing 46° Be., accompanied by 1,000,000,000 cu. ft. of gas. After testing for a few days the well was shut in, and has remained so to the present time. In five days, 2200 bbl. of oil were run to storage. The oil flowed by heads

TABLE 2.—*Oil and Gas Development of "Western" Kansas, January, 1924, to December, 1927*

Name	Location	County	Discovery Date	Number of Wells Producing	Production 1927, Bbl.	Total Production, Bbl.	Gravity, Deg. Bé.	Producing Horizons
Active Oil-producing Areas								
Fairport	S. 29 & 32; 11 S; 15 W. S. 5-7-8-17-18; 12 S; 15 W.	Russell	1923	102	944,100	4,360,299	40	Middle Pennsylvanian 9 producing horizons
Austin	S. 30; T. 12 S; R. 15 W.	Russell	1926	4	24,419	28,729	40	Middle Pennsylvanian 2 producing horizons
Gorham	S. 32 & 33; 13 S; 15 W. S. 4 & 5; 14 S; 15 W.	Russell	1926	4	67,719	73,783	37	Middle Pennsylvanian 2 producing horizons
North Gorham	S. 7; T. 13 S; R. 15 W.	Russell	1927	1	6,811	6,811	39	Middle Pennsylvanian 5 producing horizons
Rooks County	S. 3; T. 10 S; R. 16 W. S. 11; T. 9 S; R. 16 W.	Rooks	1927	2	7,800	7,800	32	Middle Pennsylvanian 2 producing horizons
Welch	S. 34 & 35; 20 S; 6 W. S. 2 & 3; 21 S; 6 W.	Rice	1924	27	624,264	923,079	32	Erosional Remnants of Mississippi Lime
Abbeyville	S. 24; T. 24 S; R. 8 W.	Reno	1927	1	15,495	15,495	37	Basal Kansas City Pennsylvanian
Latta	S. 9; T. 30 S; R. 2 W.	Sumner	1927	2			39	Layton Sand Pennsylvanian
Abandoned Oil-producing Area								
Kingman	S. 16; T. 27 S; R. 7 W.	Kingman	1926	1	4,008	27,000	31	Top Mississippi Lime
Active Gas-producing Areas								
McPherson	S. 29 & 32; 18 S; 2 W.	McPherson	1926	3		748 million		Mississippi Lime
Latta	S. 9; T. 30 S; R. 2 W.	Sumner	1927	2				Topeka Lime Pennsylvanian
Potential Gas-producing Areas								
Liberal	S. 20; T. 33 S; R. 33 W. S. 3; T. 35 S; R. 34 W.	Seward	1924 1927	3				Lower Permian
Hugoton	S. 31; T. 33 S; R. 37 W.	Stevens	1927	1				Lower Permian
Alexander	S. 13; T. 33 S; R. 13 W.	Barber	1927	1				Top Mississippi Lime?
Morrison	S. 20; T. 32 S; R. 21 W.	Clark	1926	1				Undetermined

Total Number of Oil Wells in Western Kansas 144
Total Number of Gas Wells in Western Kansas 11
Gross Production of Oil in Western Kansas 5,442,996

TABLE 3.—*Producing Horizons in Fairport Field, Russell County, Kansas**

Horizon	Remarks	Approximate Number of Producing Wells
Dodge pay	Occurs 28 ft. above top of Oswald lime. Poorest producing horizon	3
Note.—The top of the Oswald lime is the datum plane above and below which all producing horizons are measured.		
Oswald pay	Occurs 0 to 12 ft. below top of Oswald lime. Best producing horizon	102
30-ft. pay	Occurs 30 ft. below top of Oswald lime. Best producing horizon	102
45-ft. pay	Occurs 45 ft. below top of Oswald lime. Third best producing horizon	?
65-ft. pay	Occurs 65 ft. below top of Oswald lime. Fourth best producing horizon	?
75 to 85 ft. pay	Occurs 75 to 85 ft. below top of Oswald lime. Seventh best producing horizon	?
98-ft. pay	Occurs 98 ft. below top of Oswald lime. Produces over smallest area, and therefore defines first edge water. If oil is not present here, well is usually abandoned. Some 50 wells have been deepened to this horizon, but only about half have produced oil from it. Second best producing horizon	25
160-ft. pay	Occurs 160 ft. below top of Oswald lime. Fifth best producing horizon	20
220-ft. pay	Occurs 220 ft. below top of Oswald lime. This is lowest producing horizon in Fairport field. Sixth best producing horizon	?
Basal conglomerate	Occurs 280 to 320 ft. below top of Oswald lime. A total of 6 wells have been drilled into this basal conglomerate zone in Fairport field, but none have produced commercial quantities of oil	0

Note.—All wells in the Fairport field are producing from the Oswald and 30-ft. pays, but may or may not be producing from the lower horizons. It is not feasible to assign any definite number of producing wells where questioned above.

* Courtesy of Thomas H. Allan, Midwest Exploration Co., Russell, Kan.

at the rate of 250 bbl. per day, but the well is capable of making 550 bbl. daily on the swab. This is the first and only "Wilcox" sand production in "western" Kansas. This area may become one of the most important producing areas in "western" Kansas during 1928, if the well is opened and development follows.

Reno County.—Important, as well, was the completion of the Marland Oil Co. No. 1 Griffin, located in the SE corner NW ¼ of Sec. 4, -T. 26 S, -R. 4 W. About the middle of April, 1927, at a depth of 4121 ft., the top of the Viola (?) lime was encountered, containing a good oil showing through a hole full of water. The water was shut off and on May 5, after deepening 2 ft., the hole filled with 42° Be. oil and slopped over. At this time no water was present. On May 6, after swabbing

at the rate of 35 bbl. of oil per hr., for 4 hr., water began to appear again. The production record for the first few days is as follows:

May 6—122 bbl. oil and 72 bbl. water
May 7— 84 bbl. oil and 49 bbl. water
May 9— 52 bbl. oil and 34 bbl. water

Finally it was deepened to a total depth of 4348 ft. in the "Siliceous lime," without further benefit, and plugged in October, 1927. In all, it probably produced about 1500 bbl. of oil. It was the best showing during 1927 in a well which was lost, and will undoubtedly cause additional effort to be made to open a productive field at this locality.

Osborne and Edwards Counties.—Two wells were completed which revealed the presence of unexpectedly deep Pennsylvanian basins. These were Stearns & Streeter Co. No. 1 Carlin, SW corner NE ¼ of Sec. 19, -T. 8 S, -R. 13 W, Osborne County; and Henry Rosenthal No. 1 Nebergall, NE corner SE ¼ SE ¼ of Sec. 7, -T. 23 S, -R. 19 W, Edwards County.

Carlin No. 1, was drilled to 3990 ft. and passed directly from Pennsylvanian into Ordovician. Below the top of the Oswald lime, a sequence of 740 ft. of Pennsylvanian strata was found. Attention is called to the fact that this is the greatest interval, penetrated to date, between the top of the Oswald lime and the base of the Pennsylvanian.

Nebergall No. 1, was carried to a total depth of 4653 ft. The base of the Pennsylvanian was reached at 4612 ft. and was underlain by 41 ft. of cherty limestone. The age of this limestone is presumably Mississippian.

Hodgeman and Logan Counties.—From a scientific standpoint, in supplying interesting information concerning the subsurface stratigraphy at widely separated points in far-"western" Kansas, two wells were of valuable assistance. These are Spencer and Marconnette, No. 1 Frizell, SE corner NE ¼ of Sec. 19, -T. 21 S, -R. 22 W, Hodgeman County, and Andrews and Lewis No. 1, W. H. Coons Trustee, NW corner NE ¼ NW ¼ of Sec. 14, -T. 14 S, -R. 33 W, Logan County.

Frizell No. 1 was completed at a total depth of 4386 ft. in strata of Pennsylvanian age, presumably about 225 ft. above the base of the Pennsylvanian. It rendered assistance in the interpretation of the log of J. W. Thornburg, No. 1 Whiteside, NW corner SW ¼ of Sec. 2, -T. 24 S, -R. 23 W, Hodgeman County, drilled to a total depth of 4070 ft., which some years ago was thought to have encountered rocks of Mississippian age below 4034 ft.[8] Based on the examination of cuttings in the Frizell well, Whiteside No. 1 did not reach the base of the Pennsylvanian.

---

[8] P. V. Roundy: Contribution to Stratigraphy of Western Kansas. See note by K. C. Heald, in *Bull.* Amer. Assoc. Petr. Geol., (1924) **8,** No. 2, 242.

Andrew and Lewis No. 1, was drilled to a depth of 3855 ft. and stopped in strata, the age of which has not been satisfactorily determined. Presumably it penetrated into the upper Pennsylvanian. The chief value derived from this test was that it supplied concrete information on the thickness of the Cimarron group, and on the character of the Lower Permian strata at this far-western locality.

Barber County.—A deep and interesting well was completed in Barber County in the early part of 1926; namely, the Skelly Oil Co. and Merriam No. 1 Hastings, located in the SW corner of Sec. 30, -T. 30 S, -R. 14 W, and drilled to a total depth of 4746 ft. Its chief interest lies in the extremely thin section of Mississippi lime encountered, and the presence of the Tyner series. A show of oil with a hole full of water was encountered at 4620 ft. in strata of probable Ordovician age.

Core Drills and Geophysical Operations

Core drills have been operated in Kansas by several of the major oil and gas companies for some period of time. In fact, two prolific fields discovered in the past two years—Churchill and Oxford, both in Sumner County—are the direct result of this positive method of locating structural conditions favorable for the accumulation of oil and gas. During the period of greatest activity in 1927, there were approximately 34 drills operating within the state.

A number of torsion balances, seismographs and, more recently, an increasing number of magnetometers, have also been decidedly active.

The areas of unreliable surface exposures in eastern and central Kansas (the latter includes the eastern part of "western" Kansas), where "markers" may be found at reasonably shallow depths, are most suitable for core drill operations. In large areas, irregularly distributed over the far-western part of the state, it is questioned whether or not they may be used without unwarranted expense.

The western third of the state, the major part of which is covered by Tertiary deposits, resting on comparatively thick Cretaceous and Permian sediments, is best adapted to the use of geophysical instruments, because of economical operation in contrast with core drill costs. The geophysical instruments, however, are not limited to any particular area, but may be used in either the east or west divisions of the state.

Review and Outlook

Eastern Kansas

Outstanding developments in Eastern Kansas during 1927 were:

1. Discovery of the prolific Oxford pool in eastern Sumner County.
2. Discovery of the Quincy and Lamont sand "trend" pools in Greenwood County.

3. Development of Viola lime production in the Leon area of Butler County.

4. Discovery of a 200-bbl. oil well on the Lost Springs townsite in Marion County.

5. Discovery of the first oil pool in the Colony (Bartlesville) sand, north of Township 26 South, in the Shoestring area. (Heretofore, has produced gas only.)

6. Development of the Big Lake pool and the resulting increase in production in Miami County.

Many localities exist in eastern Kansas where a search for additional oil and gas reservoirs can well be carried on.

Favorable localities, untested, are present in the shoestring area.

The northeastern part of the state has its possibilities also. In a part of the area, the Cherokee shale is excessively thick and contains competent sands near its base, occasionally 100 ft. or more in thickness, which occupy the same relative position as the Bartlesville sand. Some years will probably pass before this area is sufficiently tested to furnish desirable subsurface information.

Favorable indications are present for extensions of the Greenwood and Butler County sand "trends," and for the discovery and development of additional cross-"trends."

Each year witnesses the discovery of new pools, and the development of extensions. Occasionally, new producing horizons are found. With the probable improvement of conditions within the industry, and the increasing activity resulting therefrom, there is no reason to believe that the year 1928 will prove to be an exception.

"Western" Kansas

Outstanding developments in "western" Kansas during 1927 were:

1. Discovery of oil in the "Wilcox" sand in Sumner County.

2. Development proving the presence of an important gas area in McPherson County.

3. Discovery of oil at two separate localities in Rooks County.

4. Discovery of oil in the basal Kansas City formation in central Reno County.

5. Great increase in production in the Welch field.

6. Discovery of additional potential gas areas in Seward and Stevens counties in extreme southwest Kansas.

7. Discovery (early in 1928) of a 1000-bbl. well, initial production, from a new producing horizon in Russell County.

Many other events have taken place during the year which in themselves may appear inconsequent, but collectively, they serve to indicate great potential oil and gas resources in "western" Kansas.

A sufficient number of wells have now been drilled to locate major subsurface lines of folding, which will greatly assist in a more intelligent location of future operations. They may be expected to eliminate areas where possibilities for the accumulation of oil and gas are negligible. Future proceedure will involve the discovery of local structural conditions, favorable for accumulation, along these major subsurface folds; this, by surface mapping, core-drilling, and geophysical methods. By far the greater number of wells heretofore drilled were located before the present knowledge of subsurface structure was revealed. Many dry holes may be expected, but before abandonment, all tests should be carried sufficiently deep, to preclude further possibilities of deeper oil horizons. Past records show too many wells which have penetrated almost, but not quite, deeply enough. The importance of locating tests on sound geologic evidence is emphasized since the subsurface stratigraphy and structure of "western" Kansas is intricately complex.

No oil has yet been discovered in Barber County, but extensive exploration and an intensive leasing campaign, indicate that the county will be somewhat active as soon as conditions within the industry warrant.

In McPherson and Saline counties, additional gas areas may be developed. The presence of oil in the Mississippi lime, on the flanks of the McPherson gas dome, or in "Wilcox" sand, if present, under the apical part of the structure, is still problematical, but will receive its due consideration in the near future.

The discovery of new pools in Russell County (which includes a new producing horizon), and of commercial quantities of oil in Rooks County, will add impetus to development and "wildcatting," which will involve Rooks, Ellis, Russell, Rush, Barton and Ellsworth counties.

With the discoveries of 1927 in mind, with due consideration for "near successful" tests—the indicators of a potential oil and gas region—and with improved geologic knowledge, a result of all former operations, much may be expected of "western" Kansas in the year 1928.

Acknowledgments

This paper has been prepared in accordance with the desire of the Kansas Geological Society, to present timely information to those interested in oil and gas development and future possibilities within the state. The following men contributed valuable information: Anthony Folger, Gypsy Oil Co.; Homer H. Charles, Southern Kansas Gas Co.; R. B. Rutledge, Barnsdall Oil Co.; John R. Reeves, Empire Oil & Refining Co.; Thomas H. Allen, Midwest Exploration Co.; Marvin Lee and John L. Garlough, Consulting; F. G. Holl, Consulting; Amil Anderson, Consulting; and A. M. Bell, Gypsy Oil Co. Special acknowledgment is due Mr. Charles for the information furnished relative to the Shoestring area of

eastern Kansas, and to Mr. Rutledge for his complete data on Cowley and eastern Sumner counties. The consideration of "Western" Kansas is based on voluminous data furnished by Mr. Folger. The greater part of his manuscript is incorporated intact within the paper. His great assistance is acknowledged with sincere gratitude. Production figures have been taken in large part from *Oil and Gas Journal*.

Oil Development in Oklahoma in 1927

By J. M. Sands,* Bartlesville, Okla.

(New York Meeting, February, 1928)

Production of oil in Oklahoma during 1927 amounted to 273,256,900 bbl. (Table 1), an increase of nearly 100,000,000 bbl. over the previous year. All of the major fields declined with the exception of those of the Seminole district which produced 136,105,000 bbl., almost one-half of the total production of the state. Because of this large new production, most of the development in the state during the year took place in that district.

The Seminole City pool located in T.-9-N., R.-6-E., was the first of these pools to be developed. The Indian Territory Illuminating Oil Co. brought in the first well in this field in March, 1926, for 1100 bbl. This well is located in Sec. 24-T.-9-N., R-6-E., and produced from the Hunton lime reached at depth of 3900 ft. The first Wilcox production was developed by the Independent Oil & Gas Co. and R. S. Garland in Sec. 26, T.-9-N, R-6-E. This well was being drilled for production in the Hunton lime but was dry in this horizon and was deepened to the Wilcox sand in July, 1926, and at the total depth of 4069 ft. developed a maximum production of 8000 bbl. daily. It held up in wonderful manner and was the cause of not only the development of this pool but the prospecting of the whole district for the Wilcox sand. This led to the discovery of the other major pools in that district. Seminole City pool reached a peak production of 264,500 bbl. on February 22, 1927, and slowly declined so that by December it had a daily average of 56,200 bbl. from 321 wells.

The second pool in this district to be discovered was the Searight pool which was discovered by F. J. Searight et al. in Sec. 33, T-10, R-6, in April, 1926. The first well was drilled to the Hunton lime encountered at 4115 ft., and came in for 1300 bbl. daily. During August, 1926, the second well was drilled on the same farm through the Hunton lime to the Wilcox sand which was encountered at 4360 ft. It came in for an initial production of 4000 bbl. daily. This started active drilling in this field for the Wilcox sand. The field had a peak production of 40,621 bbl. on June 15, 1927, and declined to a daily average of 22,300 bbl. from 73 wells during December.

---

* Consulting Geologist, Phillips Petroleum Co.

TABLE 1.—*Oklahoma Production by Pools, by Months, 1927 (in Barrels)*

Pools	January	February	March	April	May	June	July	August	September	October	November	December	Total
Seminole City	4,465,300	6,602,000	7,038,300	5,869,500	4,463,900	3,370,900	2,889,800	2,398,100	2,194,700	2,102,800	1,824,200	1,741,600	44,960,100
Earlsboro	289,100	495,000	987,100	1,366,800	1,976,400	2,343,200	4,715,800	5,379,000	5,025,300	5,189,000	4,922,600	4,663,400	37,352,700
Bowlegs	318,200	293,700	560,400	1,688,400	3,419,500	4,675,700	5,810,700	5,176,700	4,281,600	3,971,500	3,805,700	3,499,400	37,501,500
Searight	978,500	838,600	955,400	974,700	1,091,600	1,101,900	1,023,000	930,400	928,300	877,700	792,300	691,900	11,184,300
Little River							378,300	303,000	616,100	1,289,100	1,307,300	1,211,600	5,105,400
Total Seminole District	6,051,100	8,229,300	9,541,200	9,899,400	10,951,400	11,491,700	14,817,600	14,187,200	13,046,000	13,430,100	12,652,100	11,807,900	136,105,000
Burbank	1,479,200	1,379,200	1,467,100	1,297,200	1,348,400	1,324,100	1,247,000	1,187,500	1,083,200	1,102,600	1,154,900	1,160,000	15,230,400
Tonkawa	812,100	727,000	756,500	692,900	706,400	652,800	635,200	609,300	560,200	555,900	500,000	484,100	7,692,400
Garber	592,100	523,600	557,000	502,400	475,500	418,000	372,500	346,200	330,000	322,000	301,600	315,400	5,056,300
Cushing	665,200	594,000	659,500	636,800	663,700	643,700	664,900	662,200	637,400	659,100	637,200	652,400	7,776,100
Bristow-Slick	849,000	764,200	846,100	818,000	840,600	798,700	809,700	787,300	750,800	771,300	747,700	765,100	9,548,500
Cromwell	423,300	380,700	420,400	396,400	398,800	392,500	393,700	382,000	384,000	358,400	332,700	332,200	4,595,200
Wewoka	707,600	534,800	566,000	553,300	611,900	572,700	599,300	543,800	421,000	420,300	346,700	311,400	6,188,800
Healdton	466,800	419,700	461,100	436,100	460,500	446,400	461,800	462,600	449,300	463,500	442,200	454,300	5,424,300
Scholem-Alechem	345,600	397,000	452,200	450,400	473,300	514,900	521,800	511,900	483,200	433,800	381,000	386,500	5,351,600
All others	6,161,000	5,464,400	6,294,600	5,929,000	6,076,900	5,803,000	5,726,200	6,139,400	5,775,700	5,734,100	5,510,800	5,673,200	70,288,300
Total Oklahoma	18,553,000	19,413,900	22,021,700	21,611,900	23,007,400	23,058,500	26,249,700	25,819,400	23,920,900	24,251,100	23,006,900	22,342,500	273,256,900

The third Wilcox sand pool to be discovered was the Earlsboro field. The discovery well was drilled by the Gypsy Oil Co., the Amerada Petroleum Corpn. and the Westland Oil Co., in the Northeast Corner of Sec. 16, T-9, R-5. It encountered the Wilcox sand at 4300 ft. and made 8000 bbl. the first day. Upon being drilled deeper, production increased to 12,000 bbl. daily. The production from this well held up in a wonderful manner and it was making 8000 bbl. daily several months after being brought in. An interesting sidelight on this situation was the drilling in as dry holes of three offset wells. This field reached its maximum production of 209,874 bbl. on Aug. 10, 1927, and for December, 1927, produced a daily average of 150,450 bbl. from 285 wells.

The next pool to be discovered was the Bowlegs pool. Two wells were drilled in by the Indian Territory Illuminating Oil Co. at about the same time, the No. 1 Livingston in Sec. 15, T-8, R-6, and No. 1 Davis in Sec. 13, T-8, R-6. They were brought in during Christmas week, 1926. The Wilcox sand was discovered at about 4200 ft. Later development has discovered what is called a second Wilcox sand in this pool at a depth of from 75 to 100 ft. below the top of the first. The Livingston well had an initial output of 4000 bbl. daily and the Davis well 5500 bbl. daily. This pool had a peak production of 194,773 bbl. on July 4, 1927, and during December produced a daily average of 112,900 bbl. from 290 wells.

The Indian Territory Illuminating Oil Co. by their No. 1 House located in the Northwest Corner of Sec. 1, T-7, R-6, discovered the Little River pool, the fifth pool in the district. The well was drilled in on June 19, 1927, and at a depth of 4125 ft. had an initial output of 9300 bbl. daily. This field had a peak production of 47,152 bbl. on Oct. 20, 1927, and during December had a daily average production of 39,100 bbl. from 86 wells. The wells of this pool have not been produced to a maximum as they have not been shot, and it is expected that some increase will occur after this is done.

During the year, seven other new fields were discovered in this district but because of the immense overproduction and low price for oil, the discovery wells were held down to 100 bbl. daily each and only a very limited number of wells were allowed to be drilled in their vicinity. These new wells in the order of their discovery are as follows:

No. 1 Cindy Brown, Sec. 33, T-8, R-6, owned by Gypsy Oil Co., encountered Wilcox sand at 4539 ft. It was brought in March 29, and produced 589 bbl. the first day.

Prairie Oil & Gas Co. on the Baker farm in Sec. 24, T-9, R-5, encountered the Wilcox sand at 4315 ft. on May 23. This well made 1100 bbl. the first day.

On Oct. 14, the Gypsy Oil Co. brought in its No. 1 Dosar, Sec. 7, T-8, R-6. This well encountered the Wilcox sand at 4285 ft. and made 900 bbl. the first day.

The Independent Oil & Gas Co. and Highway Oil & Refining Co. on Nov. 6, drilled in their No. 1 Hotulka in Sec. 23, T-7, R-6. It encountered the Wilcox sand at 4323 ft. and made 2350 bbl. the first day.

Snowden & McSweeney on Nov. 24 drilled in their No. 1 Tiger in Sec. 13, T-7, R-6. The Wilcox sand in this well was encountered at 4315 ft. and the well produced 744 bbl. the first day.

On Dec. 9 the Mid-Continent Petroleum Corpn. drilled in its No. 1 Smith in Sec. 5, T-7, R-7. The Wilcox sand was encountered at 4443 ft. and the well produced 1250 bbl. the first day.

On Dec. 11 the Barnsdall Oil Co. and Wolf Oil Corpn. drilled in their No. 1 Fife in Sec. 14, T-8, R-5. This well encountered the Wilcox sand at 4292 ft. and produced 1396 bbl. the first day.

These wells have all been shut down to 100 bbl. daily because of the present shutdown in the Seminole district. Whenever this shutdown is removed or modified, development in the vicinity of these wells will become active and undoubtedly a pool around each will be developed. It is at present impossible to estimate the size of these future pools.

Developments Other Than Seminole

Another important development during the year was the discovery well drilled by the Roxana Petroleum Corpn. in Sec. 30, T-19, R-4 W, Logan County. This well encountered the Wilcox sand at 5985 ft. and had an initial output of 2300 bbl. daily. The well was brought in May 17 and produced over 300,000 bbl. during the remainder of the year. At the end of the year it was producing 2090 bbl. daily. No other wells have been finished in this district although there are several others drilling. Deeper wells have been drilled to the north, east and south of this well and encountered only small production or salt water in the Wilcox sand so that if the field is to be extensive, its productive area must be to the west.

Another important development was the discovery of a deeper sand in the Allen pool. This well was drilled by the Homaokla Oil Co. in Sec. 16, T-5, R-8. Production was coming from 2200 ft., probably from a sand of the Dutcher horizon. The well produced 300 bbl. the first day and at the end of the year 30 wells in this horizon were producing 6000 bbl. daily.

During the year the eastern extension to the Burbank field was lengthened and also joined to the original field. This narrow strip caused quite a sensation on account of the size of the wells developed. It is probable that it is not yet fully developed and will be extended still further to the southeast. However, it cannot be large and will have no appreciable effect on future production figures.

At the beginning of the year over 300 new rigs were being erected monthly; this had been reduced to about 150 by the end of the year. During the first three months of the year over 1200 wells were drilling;

this had been reduced to 716 by December. In January 250 wells were completed; 149 were completed in December. In January, the total initial production from new wells amounted to 137,487 bbl.; by July this had climbed to 289,333 bbl., and by December it had decreased to 59,647 bbl. These figures are largely influenced by the large Seminole wells so that there was a rapid increase in new production in midsummer notwithstanding the gradual decrease in number of wells drilling during the whole year. However, after the fields had reached their peak and the new wells were coming in small, the restriction in the number of new wells going down had the effect of rapidly reducing the initial production developed. Production in the Seminole district will continue to decrease as long as the shutdown in that district remains in force. There are, however, sufficient other pools in the district to materially increase production just as soon as a sufficient number of new wells are completed in these new fields.

The present depressed condition of the oil industry with its low prices coupled with the cooperative efforts of the oil men to curtail development, are causing a decline in production and a slowing down of new work in all of the older fields in the State. This condition will probably be maintained until conditions improve. It is to be hoped that cooperative efforts in the Seminole district will continue to be successful in curtailing production until such is needed.

DISCUSSION

J. M. Lovejoy,* Tulsa Okla.—The wildcat areas in Oklahoma lie chiefly to the west of Seminole. The Caddo and Canadian counties are getting a very active play; presumably there is a chance for Wilcox production north of the Wichita Mountains, and it is hoped that there may be a plateau similar to the Seminole Plateau, but there has not been enough drilling to find out just what the geological section will be in that area. But the price of acreage has doubled several times and the most of Caddo County has been blocked in large wildcat blocks, and in 1928 and 1929 there will be considerable drilling there.

East of Seminole, or rather east of Holdingville, down toward Coal County, there are some very sharp anticlines over toward the Choctaw fault which have not been entirely tested and the excitement of Seminole has caused some activity in that area. There are several wells being drilled in Coal County now.

The wildcat play is continued from Caddo County north and somewhat west as far as Wood County, which is against the Kansas line. It simply is a skirting of production to the west, which represents the whole history of Oklahoma production. Production has gradually crept west, and I think most of the checkerboarding and wildcat blocking west of Seminole and west of known production in Oklahoma has very little reason other than that they have to go west; they cannot go east.

C. N. Gould,† Norman, Okla.—The deepest well in Oklahoma so far as I know, is at Oklahoma City. This well is now down 6700 ft. It is a question whether it is on the Wilcox or whether it is a few hundred feet above the Wilcox.

* Vice-president, Amerada Petroleum Corpn.

† Director, Oklahoma Geological Survey.

Mr. Lovejoy mentioned the drilling in Coal County. There is a very marked anticline in that region, located by Mr. Taff a great many years ago, which is one of the series of the anticlines in the Coal region in Oklahoma, this being the one farthest west and nearest production.

The Indian Territory Illuminating Oil Co. has a large body of acreage and are drilling a very thorough test in that region. I was told last week by a man who keeps in touch with the situation that 20 or 22 different companies are now getting daily samples from that well. They are watching it very closely, and my judgment is that this well has a very good chance of finding production. If so, it will bring in a very large area because there is no oil now within perhaps 30 miles of this structure.

For a great many years in Oklahoma, we have liked to say that during certain months of 1915 the Cushing field produced 60 per cent. of the high grade refinable oil of the world. The world's production I believe was at that time something like 500,000 bbl. a day and Cushing produced 300,000 bbl. a day. That figure is now passe and ancient history. As your speaker has said, Seminole, on July 30, 1927, produced 527,000 bbl. of high grade, refinable oil.

J. E. Pogue,* New York, N. Y.—Mr. Lovejoy mentioned that the average recovery per acre in the Seminole district is 15,000 bbl. and he estimated that the area would ultimately yield 20,000 bbl. per acre. I have projected the decline curves of the four pools according to their symmetry and find that the accumulated production by the end of 1928 will approximate 22,000 bbl. per acre. That means that either the ultimate production of the Seminole district is going to be much higher than generally expected or else the decline must soon accelerate and thus depart from its present gentle downward trend.

---

* Consulting Engineer.

Texas-Louisiana Gulf Coast Production for 1927

By Charles Laurence Baker,* Houston, Texas

(New York Meeting, February, 1928)

The total production of petroleum in the Gulf Coast in 1927 was 54,541,180 bbl., 5,655,665 bbl. more than in 1926. The Texas total was 49,129,910 bbl. (Table 1) and the Louisiana total 5,411,270 bbl. (Table 2). Louisiana production decreased 278,028 bbl., compared with that of 1926. Spindletop produced nearly 44 per cent. of the Texas total. Initial production in Louisiana amounted to 62,865 bbl. and in Texas to 352,955 bbl.[1] The *Oil and Gas Journal* gives a total of 1145 wells

Table 1.—*Texas Gulf Coast*

Field	Completions	Producers	Gas Wells	Failures	Initial Production, Bbl.	Annual Production, Bbl.
Barbers Hill	6	4		2	1,800	68,575
Batson	41	25		16	4,070	532,870
Big Creek	26	22		4	21,741	1,223,435
Blue Ridge	56	41	1	14	22,890	1,122,395
Boling	3	2		1	835	791,255
Damon Mound						336,640
Goose Creek	47	28		19	2,931	2,979,425
High Island	8	4		4	1,815	[a]
Hockley	1			1		
Hull	82	62		20	40,114	6,220,530
Humble	1	1			3,696	1,158,300
Nash Dome	5	4		1	1,560	[a]
Orange	47	34		13	13,121	1,831,195
Orchard Dome	1	1			300	[a]
Pierce Junction	77	61	3	13	66,896	3,101,320
Saratoga	15	9		6	108	405,030
Sour Lake	28	19		9	8,359	1,634,700
South Liberty	18	13		5	2,806	1,152,755
Spindletop	145	95	1	49	147,953	21,584,795
West Colombia	7	4		3	3,910	3,535,140
Others						1,451,550
Wildcats	109	6	4	99	1,050	
Totals	723	435	9	279	352,955	49,129,910

[a] Included in production of other domes.

* Chief Geologist, Rio Bravo Oil Co.

[1] From figures furnished by *Oil Weekly*.

TABLE 2.—*Louisiana Gulf Coast*

Field	Completions	Producers	Gas Wells	Failures	Initial Production, Bbl.	Annual Production, Bbl.
Edgerly	34	26	1	7	14,426	494,590
Evangeline	39	22		17	3,025	415,240
Lockport	37	31		6	32,430	2,014,465
Starks Dome	3	2		1	3,500	*
Sweet Lake	1	1			1,800	*
Vinton	42	31		11	6,801	1,897,470
Others						589,505
Wildcats	24	4		20	883	
Totals	180	117	1	62	62,865	5,411,270

* Included in production of other domes.

completed or abandoned during the year. The *Oil Weekly* states that 903 tests were drilled during the year, of which 552, or 61 per cent. were producers (the same percentage as in 1926), 10 or 1 per cent. were gas wells and 341, or 38 per cent., were failures. The greatest annual Gulf Coast production was in 1927, the next greatest in 1926. Total gross production of the Gulf Coast from the beginning of production to the end of 1927 amounted to 642,550,000 barrels.

The deep flank sands at Spindletop, discovered by the Yount-Lee Oil Co. in November, 1925, have yielded to the close of 1927, a total of 36,423,076 bbl. and were still producing 46,000 bbl. a day at the beginning of 1928. Most of this production was under the stimulus of competitive drilling, but considerable prospective area to the north and east of the competitive section is yet to be developed. Most of the oil has been produced from Miocene sands but production in the Oligocene was developed during 1927. The Rio Bravo Oil Co.'s T. & N. O. R. R. Right-of-Way Lease at Spindletop had produced over 2,000,000 bbl. per acre up to Feb. 8, 1928. Increases in Gulf Coast production during 1926 and 1927, were mainly caused by the flush production of Spindletop.

LOUISIANA

Notable new developments in Louisiana may be summarized as follows: Several good wells were completed on the northeast side of the Edgerly field and the existence of a salt dome there was first proved during 1927. The northwest side of the Jennings (Evangeline) field yielded new production at the shallow depth of 1600 ft. The Lockport field, south of Lake Charles, yielded 34 new wells during 1927. Oil was discovered on two new domes: Starks, in Calcasieu Parish and Hackberry in Cameron Parish. Starks production comes from the north flank, at

depths ranging from 4249 to 4794 ft. The Hackberry production comes from Kelso Bayou, 3 miles east of the original development, the production coming from a sand at 3971 to 3996 ft. The deepest production in Louisiana comes from Sweet Lake, Cameron Parish, at 5897 ft. A test on the new White Castle Dome in Iberville Parish found an oil sand at 1580 to 1589 ft. The two wells brought in on Sulphur Dome, Calcasieu Parish, did not produce long. There were two more producers at Fausse Point.

Texas Outside of Spindletop

In Texas, outside of Spindletop, the northwest and east flanks of Pierce Junction made notable gains in production under stimulus of partial competitive drilling on small holdings. A new producing sand was discovered at Pierce Junction, either near or in the base of the Oligocene. A number of good wells were completed at Blue Ridge and a substantial gain in production occurred at Big Creek, Fort Bend County. Sands running as low as 5000 ft. on the southwest flank of Sour Lake proved disappointing as well as drilling on the northwest side of Batson and north side of Humble. Some shortlived production was obtained on Allen Dome. Nash Dome, Brazoria County, now has 17 producing wells and a daily production of about 3000 bbl. An old well in the Kingsville area of south Texas increased notably in production. The Raccoon Bend district of Austin County produced a little oil and gas, an apparently better well coming in February, 1928. A new deep producing sand was found at 4170 ft. on the south side of the old shallow production at Dayton in Liberty County. Goose Creek maintained fairly steady production the last half of the year. The other fields decreased fairly steadily during the year, most of them exhibiting a normal decline under lack of incentive for new development, price of oil being unsatisfactory. The most spectacular decline was shown by Spindletop, which, though by no means uniform, amounted to three-sevenths the daily peak attained at the beginning of 1927. Most of the competitive drilling, aside from deepening old wells, ceased there by the middle of the year.

South Texas Natural Gas

There was enormous expansion in natural gas reserves in this area during 1927. A new gas production was found at 2400 ft. 4 miles to the west of the Cole field in Webb County. A new field, with two sands at 1416 and 1948 ft., was found south of the old Jennings gas field in Zapata County. Another gas field was discovered between Jennings and the Mirando Valley oil field, the sand being below 1300 ft. The Alworth pool on the western edge of Jim Hogg County has both oil and gas. The

O'Hern and Seacord pool has been joined up with the Cole pool to the north by intermediate producers. The Albercas pool in Webb County was found.

The largest development in the older gas fields has been in Refugio and White Point. At Refugio late in 1927 a new and deeper gas sand was found at 3300 ft.; some shallow sands were also found, and early in 1928, a new gas field was opened at a depth of 2300 ft. 5 miles east of former production. Twelve wells with 450,000,000 cu. ft. of initial production, coming from three sands, were completed in the old White Point area and on the south side of the bay in the Saxet field, four wells yielded 100,000,000 cubic feet.

Sulfur Developments

A large reserve of sulfur has apparently been proved in the caprock of the Boling Dome, Wharton County, Texas. The Long Point Dome of Fort Bend County, Texas, is apparently a promising sulfur prospect. The Clemons Dome in Brazoria County and the Big Hill Dome in Jefferson County, both in Texas, are being prospected for sulfur. Prospecting in the Allen Dome, Brazoria County, Texas, was abandoned.

Domes Discovered by Geophysical Methods in 1927

Geophysicists announced the discovery of six new supposed salt domes in Texas (Fig. 1) and 14 new supposed domes in Louisiana (Fig. 2), bringing the total probable number in South Texas to 41 and in South Louisiana to 33 or a total of 74 for the south part of the two states. Following the discovery of large initial but rapid decrease to a small settled production in a well on the Boggy Creek Dome in the interior dome area of Texas, six new supposed domes, two later proved by drilling, were announced in that area. One new dome was proved by drilling in North Louisiana. More new domes were found in Texas and Louisiana in 1927 than in any previous year. It is supposed most of the shallower domes are now found but a number of deeper ones may yet be found.

One of the new domes in Texas (Yegua Creek or Ferguson, in Washington County) is situated inland from the coast near the Catahoula-Oakville contact. Its presence is well indicated both by topography and surficial geology.

The supposed new domes in South Texas are the DeWalt (Sugarland) supposed to be a deep-seated dome, San Felipe, Lost Lake, Almeda (?), and Young Ranch (?). Of these, Lost Lake and DeWalt are now being drilled.

The announced new domes in Louisiana are Port Barre, Bayou de Glaise, Bayou Henry, Bayou Sorrell Bay, Bayou Blue, White Castle, Bayou Choctaw (Grosse Tete), Sorrento (McElroy), Donaldsonville

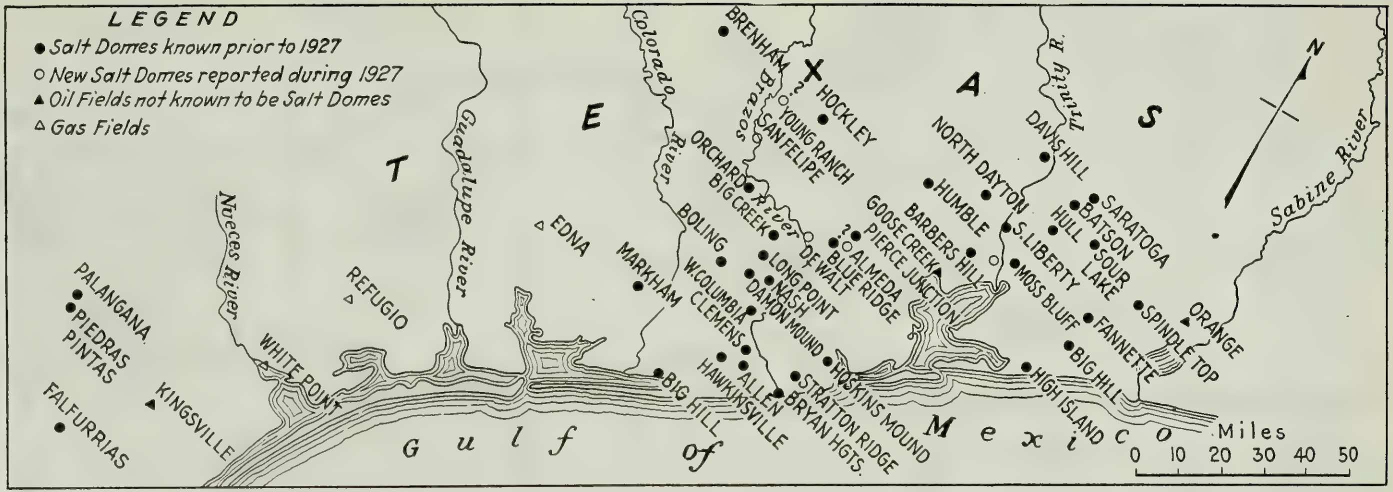
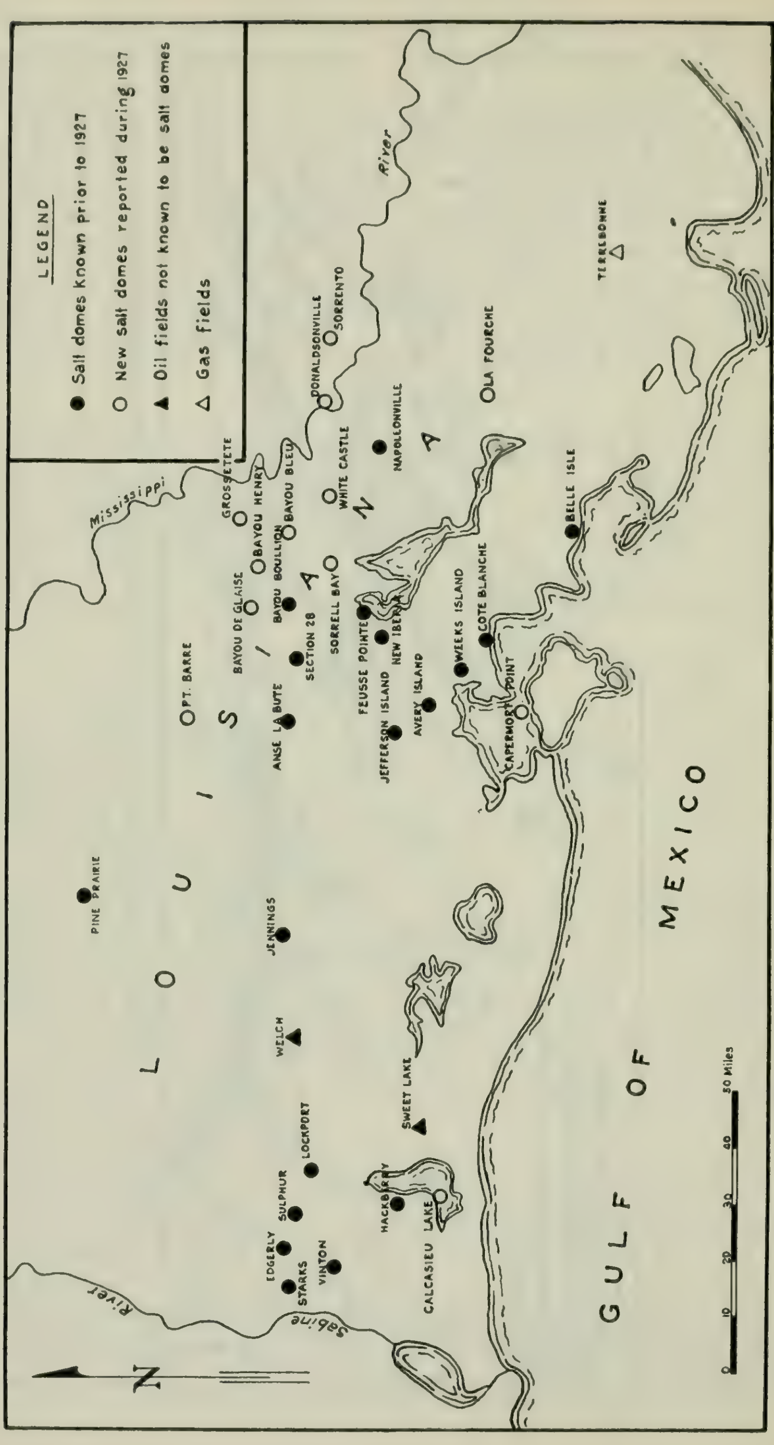


FIG. 1.—SOUTH TEXAS SALT DOMES, OIL FIELDS NOT KNOWN TO BE SALT DOMES, AND GAS FIELDS.



—LOUISIANA SALT DOMES, OIL FIELDS NOT KNOWN TO BE SALT DOMES, AND GAS FIELDS.

(Darrow), Lutcher (La Fourche), Vermillion Bay (Cypremort Point), Calcasieu Lake and two others, the situation of which have not been announced. Sorrento has been proved and has yielded both caprock oil and gas. White Castle shows both oil and gas. Salt was reached at 808 ft. in Vermillion Bay Dome. Sorrento Dome is east of the Mississippi River.

A number of the domes announced have not been tested by the drill, very few operators being desirous of increasing production during the present unsatisfactory market for oil. Data on salt domes found by geophysical means follow.

New Salt Domes Announced in Louisiana Gulf Coast

	Location	Parish	Development
Bayou Blue	Southeast part, Twp 9 S—R 10 E	Iberville	Well Drilling
Bayou Choctaw (Grosse Tete)	Near center Twp, 8 S—R—11 E	Iberville	
Bayou de Glaise	Near east line, Twp 8 S—R 8 E	Iberville	Well Drilling
Bayou Henry	Southwest corner, Twp 8 S—R 10 E	Iberville	
Bayou Sorrell Bay	Line between Twps 10 and 11 S—R 10 E	Iberville	
Calcasieu Lake	8 miles south of Kelso Bayou	Cameron	Well Drilling
Cypremort Point (Vermillion Bay).	13½ miles southwest of Cote Blanche	Iberia	Well encountered salt rock at 808 ft., no caprock, volcanic ash directly above salt
Donaldsonville (Darrow).	On Mississippi River at crossing 91st Meridian, Twp 10 s—R 2 E	Ascension	
Lutcher (La Fourche)	Southwest part Twp 15 S—R 15 E	La Fourche	Second test drilling; first failure
Port Barre (Hazelwood)	Near middle east line, Twp 6 S—R 5 E	St. Landry	
Sorrento (McElroy)	South of Middle, Twp 10 S—R 4 E	Ascension	Four tests, oil and gas found
White Castle	Northwest part, Twp 11 S—R 12 E	Iberville	Gas and oil found in well drilling

New Salt Domes Announced in Texas Gulf Coast

	Location	County	Development
Almeda (?)	4 mi. south of Pierce Jct. Dome	Harris	
De Walt (Sugarland)	10 mi. southeast of Sugarland	Fort Bend	Well Drilling
Lost Lake	Halfway between and slightly south of line between Barbers Hill and Moss Bluff	Chambers	Well Drilling
San Felipe	On Brazos River, east of Sealy	Austin-Waller	
Young Ranch (?)	10 mile north of Pattison	Waller	

Present Status of Domes Discovered by Geophysics Prior to 1927

Louisiana:

Fausse Point	3 producers, salt at 1394 ft., discovery depth 1100 to 1180 ft.
Kelso Bayou	2 producers, one well lost by gas blowout, discovery depth 3996 ft. Salt or caprock unknown.
Napoleonville	2 tests, no production, caprock at 450 ft.
Starks	4 producers, 15 tests drilled, discovery depth 4200 ft.

Texas:

Allen	2 short-lived producers, 9 tests drilled, discovery depth, 5131 ft.

Clemens	11 tests, no producers, caprock at 584 ft.
Fannett	16 tests, no producers.
Hawkinsville	20 tests, no producers.
Long Point	40 tests, no producers.
Moore's Field (Orchard)	3 producers, 14 tests, discovery depth 3750 ft.
Moss Bluff	At least 3 tests, no producers, caprock at 674 and 835 ft.
Nash	45 tests, 20 producers, total present production 3,000 bbl. daily, discovery depth, 4127 ft.

DISCUSSION

J. M. LOVEJOY,* Tulsa, Okla.—It seems to me that the development of these salt domes in the Gulf Coast is of as great importance to the oil industry as any other work that is being done. It means that the companies are building up a definite reserve of oil.

D. C. BARTON,† Houston, Tex.—The number of geophysical domes in the area of the coastal group of domes is as follows: domes in which the salt or caprock has been drilled into, 16; domes which have not been drilled, in which the wells are not yet deep enough nor correctly located to go into the salt, 12; domes not yet acknowledged but strongly suspected to have been found, 4 or more; total, 32. In the area of the interior group of domes in Texas, 7 salt domes and 3 structural highs that probably indicate the presence of the non-piercement type of salt dome have been found and two of the salt domes proved by drilling.

J. M. LOVEJOY.—Most of those domes are owned by one company or perhaps in some cases by two or three, but in general they are in large leases and it will be possible to develop them by unit operation.

The very recent discovery of oil in a salt dome east of the Mississippi, of course, is of vast importance. It means that the development of the Gulf Coast salt domes is going to swing around that entire area and we do not know how much farther it will go.

D. C. BARTON.—My theory on the subject is that it will not go east of the west edge of the southward prolongation of the Appalachians. The Appalachian Mountains come down and stop in the middle of North Central Alabama, where they are seen dipping under the Coastal plain, heading straight for the Gulf.

Now several theories to the contrary, I do not want to bend them back up into Arkansas and Oklahoma. It seems to me they must go on straight down to the Gulf, and there is a possibility that this may have marked an old highland mass at whatever time the salt was deposited, and therefore we will not find any salt domes east of the meridian through central Alabama.

There has been quite a lot of shooting with the seismic method in Mississippi. I have not scouted it and do not know just where it has been. The Dixie Oil Co. shot more than a million acres there, and according to scout reports have not picked up any dome. The Dixie Oil Co. has not issued any statement as to whether or not the report is correct.

The unit operation, the result of geophysical work in allowing blocking of a whole structure by one company, is one of the most interesting results of geophysical work. The Moss Bluff dome is held by several companies and several others are not held solidly but most of the geophysical domes are solidly controlled by one company.

* Vice-president, Amerada Petroleum Corpn.

† Geophysical Research Corpn.

J. M. Lovejoy.—In miles how far would that be?

D. C. Barton.—It is 175 miles from Sorrento east to that line of prolongation of the Appalachians, but there has been quite a lot of shooting in that area apparently without the discovery of any domes. I think there is a possibility of the salt dome area extending into southwestern Mississippi. If they go that far there is no reason now know why they should not go a little farther and perhaps as far as Alabama, but it should be noted that in Texas, the main coastal group of domes stops rather abruptly on a meridinal line about 70 miles west of Houston for no known very clear reason and that there is a barren gap of 150 miles between that line and the area of the South Texas domes. It is entirely possible that the coastal group of Texas-Louisiana domes will stop as abruptly on the east as they do on the west. The absence of the reports of mounds in southern Mississippi similar to the very distinct mounds of many of the coastal group of domes would seem to suggest the absence of salt domes in that area. The circumstantial evidence of the symmetry of the occurrence of the coastal group of domes would suggest that salt domes may be found throughout the area of the Mississippi delta and possibly off the Mississippi shore but not on land in Mississippi or north of Lake Pontchartrain in Louisiana.

J. M. Lovejoy.—I understood you to say there are three domes now proved for production which have not been developed as yet but which have oil or gas.

D. C. Barton.—Two or three wells drilled at East Hackbury are producers and there is that single well at Sorrento. There have been several producers completed at Starks, and there have been a few wells at Fausse Pointe. [Since the February, 1928, meeting, the Rycade Oil Corpn. has completed a 2400-bbl. well on Bayou Brullion on an old known dome in the Atchafalya swamps not quite halfway between Sorrento and Jennings, which is the eastermost of the old proved prolific oil fields.]

J. M. Lovejoy.—Would you say then that you have a potential field ready to be developed right now?

D. C. Barton.—Starks started out as if it were going to be a first-class field. Last summer I gave the potential production as 50,000,000 bbl. At the present time I would probably cut down to 25,000,000 bbl., but the next well may raise it up. East Hackberry I guess has a minimum of 10,000,000 bbl. Sorrento looks to me as if we—on the basis of the first well, which is a good caprock well—might guess that it would have about 50,000,000 barrels.

Production in West Texas Permian Basin for 1927*

By A. R. Denison,† Fort Worth, Texas

(New York Meeting, February, 1928)

Foreword

To those who are unfamiliar with the nomenclature in common use among operators in the Mid-Continent, the Permian Basin is a term to cover several widely separated productive areas. It includes what is designated in trade journals as the Panhandle fields, the West Texas fields and Southeastern New Mexico fields. It is bounded roughly on the east by the 100th parallel, on the west by the 104th parallel, on the south by the Rio Grande River and various mountain ranges and on the north by the north line of the Texas Panhandle. The name is derived from the location of these three widely scattered areas which are all in a broad geosyncline which is chiefly filled with sediments of Permian age. The oil fields as now known and the approximate limits of the Permian Basin are shown in Fig. 1.

The major part of the production in these areas comes from limestone or dolomite of Permian age. Some granite wash and sandstone production has been developed but ordinarily does not yield as large initial production as the limestone or dolomite.

Introduction

During 1926, Texas, exclusive of the Gulf Coast, produced 126,774,-952 bbl. of oil,[1] of which 40,727,877 bbl., or 32 per cent., was produced in the West Texas Permian Basin. During 1927 the same area in Texas produced 167,176,000 bbl.[2] of oil, of which 89,779,000 bbl.,[3] or 52 per cent., was produced in the West Texas Permian Basin. The increase in the total production of Texas is about equivalent to the increase in production in the Permian Basin. Since production in the Panhandle District declined during the entire year, the increase of production in the West Texas Permian Basin, and also the increase in Texas, is due to the enormous increase from the West Texas fields. Daily average production in the West Texas fields increased from 68,211 bbl. on Jan. 8 to

* Permission of the Amerada Petroleum Corpn.

† Division Geologist, Amerada Petroleum Corpn.

[1] R. B. Whitehead: Oil Produced in Texas during 1926 Exclusive of the Gulf Coast District. Petroleum Development and Technology in 1926, 649.

[2] U. S. Bureau of Mines.

[3] *Oil and Gas Journal.*

271,619 bbl. on Dec. 17, 1927. During the same period the Panhandle fields decreased in daily average production from 138,742 to 83,210 bbl.

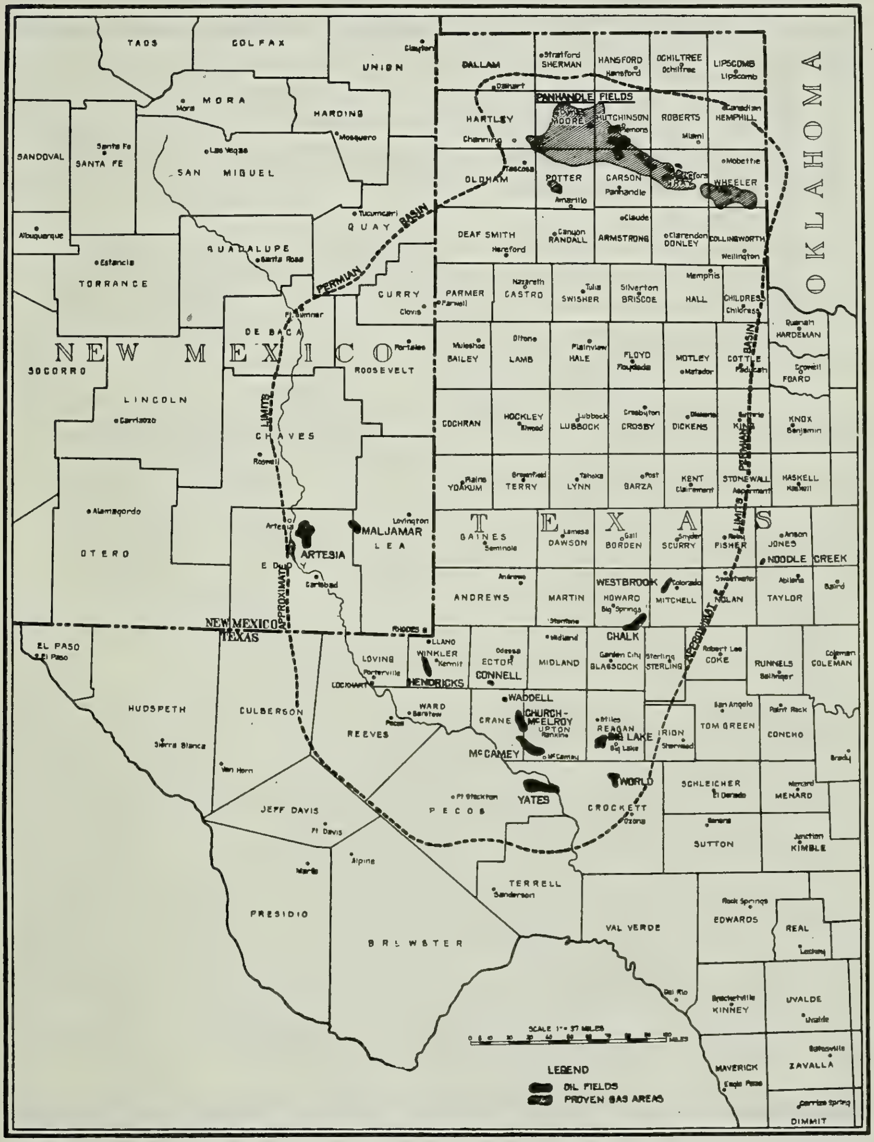


FIG. 1.—MAP SHOWING OUTLINE OF PERMIAN BASIN WITH THE OIL AND GAS FIELDS.

This gives a net gain of 147,876 bbl. per day for the two districts at the close of 1927. Fig. 2 is an analysis of the daily average production of the Permian Basin. It shows separate daily average production for the

West Texas and the Panhandle areas and a composite curve giving a total daily average of the combined Panhandle and West Texas areas.

The Permian Basin is best grouped under three heads for detailed discussion: First, the Panhandle or Northern Basin area, which includes

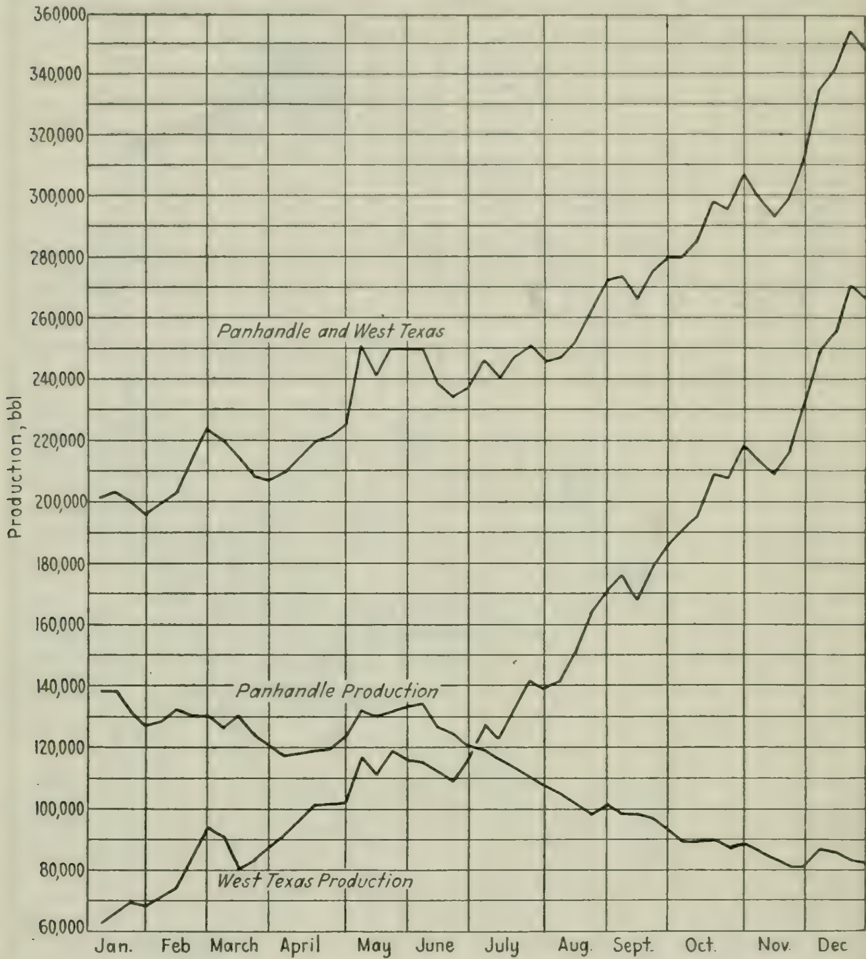


FIG. 2.—ANALYSIS OF PRODUCTION IN PANHANDLE AND WEST TEXAS, AND COMBINED PANHANDLE AND WEST TEXAS, FOR 1927.

Hutchinson, Carson, Gray, Wheeler, Potter, Oldham and Hartley counties; second, the Southern Basin area, which includes Pecos, Crockett, Reagan, Crane, Upton, Ector, Winkler, Loving, Mitchell, Howard, Glasscock, Scurry and Garza counties, and third, the West Basin, which includes the Artesia and Maljamar producing areas in Lea and Eddy counties, New Mexico. This last area is in New Mexico and will not be discussed in this paper, it being part of the Rocky Mountain region.

Panhandle Division

In this division 804 wells were completed of which 625 or 77 per cent., were oil wells and 94, or 11 per cent., were gas wells. At the beginning of the year 804 wells were producing 131,500 bbl. per day, an average of 163 bbl. per well, while at the close of the year 1429 wells were producing 80,335 bbl. per day or 56 bbl. per well. A total of 40,084,780 bbl. of oil was produced in the Panhandle Division. Of this amount Hutchinson County furnished 32,230,493 bbl., Gray County was second with 3,966,-412 bbl., while Carson County was a close third with 3,203,293 bbl.

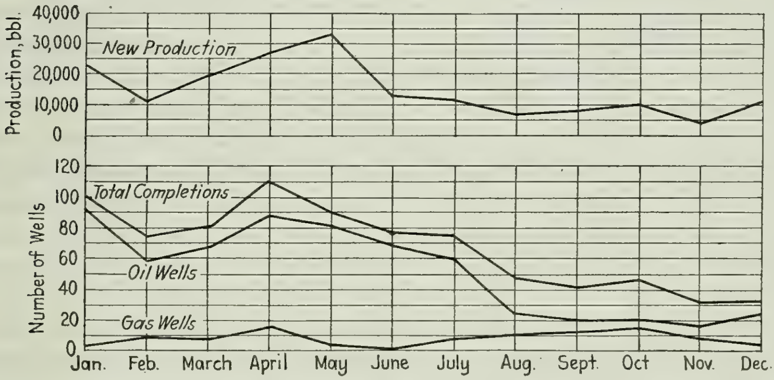


Fig. 3.—Analysis of new production, total completions, oil wells and gas wells for Panhandle in 1927.

These figures represent a gain of 15,834,780 bbl. over 1926 when the entire Panhandle produced 24,250,000 bbl., practically all of which came from Hutchinson County. The peak of Panhandle production was reached in the week ending Nov. 18, 1926, when the daily average was 161,500 bbl. It declined rapidly until January, 1927. During 1927 it declined more slowly falling below 100,000 bbl. per day for the first time on Aug. 30, and having 80,235 bbl. per day on Dec. 31. Fig. 3 is an analysis of development in the Panhandle area. It shows the amount of new production developed month by month, total number of completions, total number of oil wells and total number of gas wells.

While no new large areas comparable with the original Borger pool were developed, four new small pools were opened. They are: The Sanford or Merchant pool, 4 miles west of the Borger pool in southwestern Hutchinson County; the McIlroy pool 3 miles southeast of the Borger pool near the center of the south line of Hutchinson County; the Saunders Pool, 2 miles northeast of the Pampa Pool; the Bowers Pool, 2 miles south of the Pampa pool, both in western Gray County. Extensions have been made to several of the old pools notably in Wheeler and Carson counties.

Two initial production records for the Panhandle were established during the year. The largest oil well completed to date is the McIlroy Oil Co. No. 1 E. Cockrell, Sec. 4, Block B-3, D. & S. E. Survey, McIlroy Pool, southeastern Hutchinson County, which came in April 23, 1927, for more than 500 bbl. per hour. The largest gas well completed to date is Watchorn Oil & Gas Co. No. 1 T. E. Shelton, Sec. 22, Block 24, Shamrock area, Wheeler County, which came in making 200,000,000 ft. of gas from 1905–26 feet.

Moore County had considerable drilling which developed three small oil wells and several gas wells. Structural conditions are favorable in this county and 1928 may see the development of one or more oil pools,

Gray County was the most active area of the Panhandle during 1927. In addition to the two pools discovered, several wildcats were completed as producers in the eastern half of the county and oil fields may develop around these discoveries. The crude in Gray County is the best quality yet found in the Panhandle. It is from 42° to 44° Bé. gravity and very low in sulfur content, comparing favorably with other Mid-Continent high gravity crudes in refining qualities. Because of its superior quality it brings a premium over the other Panhandle crudes and is in great demand.

Wildcat activities outside of producing counties continued, Oldham, Hartley, Dallam, Sherman and Hansford counties being the most active. Results were very discouraging and the trend of activity is now toward drilling in the semi-wildcat areas adjacent to producing fields. Development in Gray County has directed attention to the south side of the granite ridge. This side has always been considered as offering good possibilities for production, but drilling so far has been negative. The present year may see extensive prospecting in southern Carson in an effort to develop south side production.

Drilling this year has served not only to develop and extend oil production but has done much to outline the proved gas territory, shown on Fig. 1. Almost 1,000,000 acres are now proved for gas, making this the largest gas reserve in the world. The outlining of this gas reserve led to extensive gas line building. Five trunk lines are built or are under construction which when completed will aggregate 950 miles in length. They will serve such distant cities as Denver, Colo.; Wichita, Kan.; and later Kansas City, Mo.

Three trunk oil pipe lines were built into the Panhandle during 1927. They did much to relieve the congestion caused by overproduction. It was not, however, until late in September when the daily production had dropped to 93,000 bbl. that more oil was moved than was produced. The stocks of crude in the Panhandle were not materially reduced, however, due to the large movement of oil from West Texas which took precedence with the major pipe lines.

Unless new fields of major size are discovered, the Panhandle will not produce as much oil in 1928 as in the past year. Much semi-proved acreage remains to be drilled and large areas favorable for wildcat drilling still remain to be tested.

During the latter part of February and the first part of March, 1927, the price of Panhandle crude was cut an average of 25 c. per bbl. This cut caused an immediate reduction in the number of drilling operations. A further cut on Aug. 24 brought the price of crude to an average of 45 c. less than that of Jan. 1, 1927. Improvement of the oil market in 1928 would immediately stimulate extensive exploration with the probability of developing new pools.

The Panhandle field from its beginning to Jan. 1, 1928, has produced in excess of 66,287,000 bbl. Of this amount Hutchinson County has produced more than 56,240,000 bbl. Estimates of ultimate recovery from the Panhandle fields have been materially reduced due to the rapid and widespread encroachment of water during 1927, but it still remains as one of Texas' greatest oil reserves.

West Texas Fields

In this division 915 wells were completed in 1927 of which 666 or 73 per cent. were oil wells. These had a total initial production of 1,058,948 bbl. or an average initial production in excess of 1500 bbl. per well. These figures may be too high since the initial production on the largest wells is based on gages of from 1 to 5 hr. duration after being shut in for several days. At the beginning of the year 553 wells were producing 62,811 bbl. per day or 113 bbl. per well. At the close of the first week in January, 1928, 1224 wells were producing 260,753 bbl. per day or 213 bbl. per well. While this is a substantial increase in per well average, it does not represent the true well average since the majority of the largest producers are in the Yates pool which is pinched to a fraction of its potential production. This division produced a total of 49,689,657 bbl.[4] in 1927 as compared with 16,477,327[5] in 1926. The comparative yields are shown in the following table:

	1926,[4] Bbl.	1927,[5] Bbl.
Reagan County (Big Lake)	12,227,260	8,668,381
Crane-Upton (McCamey-Church-McElroy)	2,471,246	29,583,131
Mitchell (Westbrook)	1,230,842	1,358,280
Crockett (World)	333,453	549,486
Pecos* (Yates)		5,250,173
Winkler* (Hendricks)		3,109,523
Howard*-Glasscock* (Chalk)		1,127,269
Miscellaneous	214,516	32,904
Totals	16,477,327	49,689,657

* Listed as Miscellaneous in 1926.

[4] *Oil and Gas Journal.*

[5] R. B. Whitehead: *Op. Cit.*

It will be seen that all producing counties gained with the exception of Reagan. The largest gain was in Crane and Upton counties, which is due to the development of the Church & Fields and Gulf-McElroy pools.

Fig. 4 is an analysis of development in the West Texas area. It shows total new production, number of completions, number of oil wells

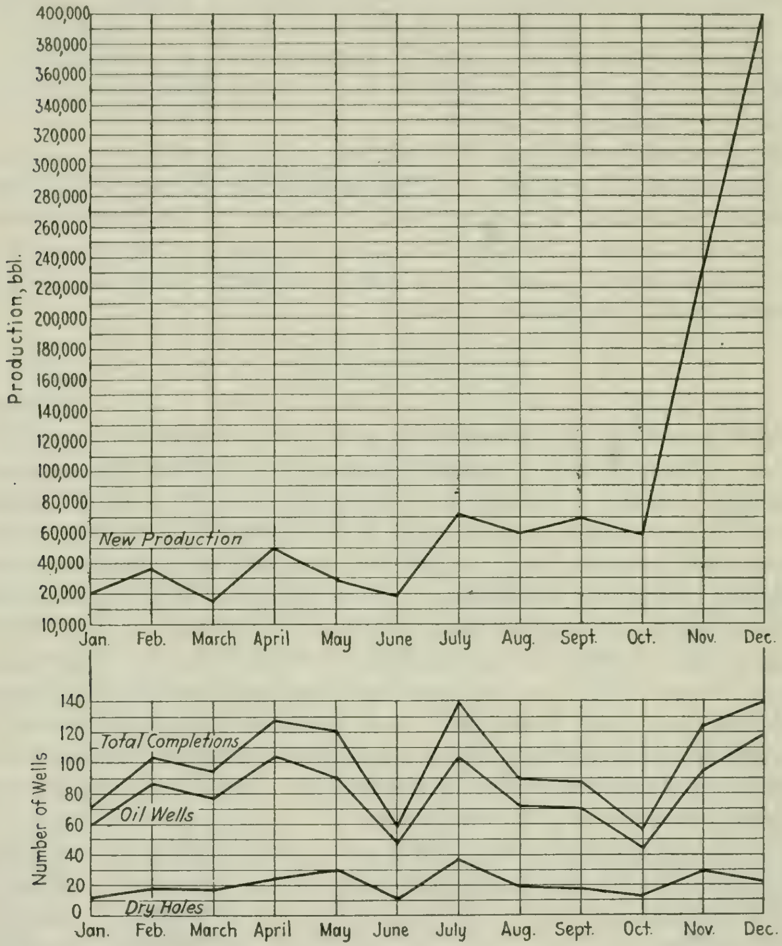


FIG. 4.—ANALYSIS OF NEW PRODUCTION, TOTAL COMPLETIONS, OIL WELLS AND DRY HOLES FOR WEST TEXAS IN 1927.

and number of dry holes in monthly intervals. The most unusual feature of this analysis is the abrupt rise in total new production which began in October. This rise is a reflection of the great stimulus given to development both in Yates and in the Hendricks pool by the encroachment of water and the completion of pipe lines.

Increased production in West Texas in 1927 was largely the result of development of pools discovered during 1926. The important discoveries of 1927 are in order of their importance: The Gulf Production Co.'s Waddell No. 2, Sec. 10, Block B-25, Public School Land, Crane County, about 10 miles northwest of the Church & Fields and Gulf-McElroy pools showed oil on Aug. 2 at 3221 ft. from the regular "Big Lime" pay. On Aug. 6 it flowed 50 bbl. from 3246 and was later completed as a 30-bbl. well on the pump. Although it is a small well, it is in the same trend as Yates, McCamey, and Church & Fields-Gulf-McElroy and is thought to represent the opening of a new pool. No offsets to this well were drilled in 1927.

The Llano Oil Co.'s Scarborough No. 1, Sec. 1, Block C-22, Public School Land, about 10 miles north of the Hendricks pool, Winkler County, showed oil at 2990 ft. on May 15. At 3060 ft. it had 600 ft. of oil in the hole. It found a second pay at 3125 and on July 17 swabbed 115 bbl. It was later drilled deeper finding sulfur water. It was plugged back and after shooting made a small well on the pump. There is some disagreement as to whether this oil was found in the "Big Lime" since it is of higher gravity than the majority of "Big Lime" oil and is very low in sulfur content. Four miles north of this well the Texas Co. No. 1 Rhodes, Sec. 22, T. 26 S., R. 37 E., Lea County, New Mexico, had formations similar to those found in the Scarborough No. 1. It found gas in sand at 3105 and 3131 ft. Deepened to 3160 ft. the gas increased and after blowing a few days began to spray oil. It is now making 25,000,000 ft. of gas and 100 bbl. of oil. The production is similar to that found in the Scarborough No. 1, being of a very low sulfur content. These wells give good indications of a new pool of better quality crude than most of the oil now produced in West Texas.

Production in the "Big Lime" was opened in the Chalk pool, Howard County, by the Magnolia No. 1 Dora Roberts, Sec. 136, W. & N. W. R. R. Survey. This well started producing on Oct. 24 from a depth of 2960 ft. At a total depth of 2976 ft. it flowed 3500 bbl. per day. The pay is about 850 ft. below the top of the "Big Lime" which is deeper in the lime than most of the production previously found. This well started considerable drilling activity and two good producers were brought in offsetting this well early in February, 1928.

A discovery of large importance to future drilling in West Texas was made in July by the Texon Oil & Production Co. 1-B, Sec. 36, Block 9, University Land in the Big Lake Pool, Reagan County. This well had 1500 ft. of high gravity crude in the hole from 6267 ft. It was not sufficient to make a producer, however, and the well is now drilling deeper being below 7200 ft. on Jan. 1, 1928. It is thought that this oil is coming from the Pennsylvanian and may indicate possibility of production below the Permian "Big Lime" elsewhere in the Basin.

Glasscock County was added to the list of oil producers by an extension of the Chalk pool in Howard County.

Runnels County was likewise added to the list by a well making 80 bbl. per day of high gravity non-sulfur crude from a depth of 2550 ft. This well is an extension westward of the Central Texas production and is producing from beds of Pennsylvanian age.

In addition to the new discoveries, several old pools were extended. The McCamey field was extended northwest in the early part of the year by wells of high initial yield. During the summer large wells were completed which extended this field southeast. Wells in both of these extension areas declined rapidly due to water encroachment.

The Chalk pool in Howard County was extended south and west by small wells in a pay at about 1300 feet.

The World pool in Crockett County was extended 1 mile south by a well making 500 bbl. initial. Four other smaller wells were completed in this extension in 1927.

The Noodle Creek pool in Jones County which was discovered late in 1926 was a disappointment and never reached major proportions.

Three discoveries in 1926 developed into major pools in 1927. The following is a brief description of their development:

Church-McElroy, Crane County.—At the beginning of 1927 two small areas in eastern Crane County about 4 miles apart were producing. One was owned by Church & Fields, the other by the Gulf Production Co. on the McElroy ranch. They were at that time considered to be on separate structures. Subsequent drilling proved them to be one field on the same structure. For this reason the name "Church-McElroy" is suggested for the now continuous productive area.

Competitive drilling caused rapid development of the field. For the week ending Oct. 8 it reached its peak production of 117,040 bbl. per day after which it declined slowly for the remainder of the year. The north end of the pool is defined but much favorable territory still remains to be drilled in the south or McElroy end.

Yates Pool, Pecos-Crockett Counties.—Production in the Yates pool comes from the regular "Big Lime" pay which is found at a depth of 850 to 1600 ft., depending on location on structure and topography. Wells of tremendous initial production are found at shallow depths. The largest well gaged to date is the Mid-Kansas Transcontinental No. 2-C-Yates, Sec. 60, Block 1, I. & G. N. R. R. Survey. This well made its first oil from a pay above the "Big Lime" at 560 ft. on Oct. 28. Deepened to 960 ft. it made 167 bbl. per hr. It was then deepened to 993 ft. and on Nov. 15 flowed 2059 bbl. in 45 min. or at the rate of 65,880 bbl. per day. From Nov. 15 to Dec. 1 it was pinched to a fraction of its capacity and when opened for a proration gage made 2388 bbl. in 1 hr. or at the rate of 57,312 bbl. per day. While this is the largest

well by hourly gage, Simms Petroleum Co. No. 2 Smith, Sec. 103, made 10,000 bbl. in 5 hr. or at the rate of 48,000 bbl. per day.

Two wells were producing in the Yates pool at the beginning of 1927. Development progressed slowly due to the lack of pipe line facilities. Only nine producers were completed up to the last week in June. Wells with exceptionally high initial production were brought in and pinched to a fraction of their capacity. Drilling was given great impetus late in September by the appearance of water on the east end of the structure, and the completion of a trunk pipe line.

Early in the development of the field, a proration agreement was entered into in an effort to curtail development and confine production to the available pipe line outlet. This agreement which was based upon periodic hourly gages of all producing wells, proved unsatisfactory, as it served to stimulate rather than retard development. On Jan. 1, 1928, a new agreement was made, using proved acreage rather than hourly gages as a basis for proration of runs; and at this time the scheme seems to be accomplishing the desired result.

During November 35 wells were completed in the Yates pool. On Dec. 1 a total of 69 wells were gaged under the existing proration agreement. They produced 25,207 bbl. in 1 hr., an average of 365 bbl. per well per hr., giving a potential production of 604,968 bbl. per day, or a well average of 8767 bbl. per day. This potential production is thought to be at least double the amount these wells would produce if allowed to flow for 24 hr. By Jan. 1, 1928, 103 wells were producing with an estimated potential production in excess of 800,000 bbl. per day. A daily average of 46,705 bbl. was run by pipe lines during the last week of 1927.

This field now has a proved length of 7 miles and an average width of 2½ miles. It is roughly defined by dry holes or wells making water, on all sides except the north. The largest initial production so far has been from wells on the north side of the structure, which apparently has a steeper dip than the south. Although estimates of total recovery were greatly reduced late in 1927 by the menace of probable water encroachment, this field, due to its shallow depth and high initial production, will probably rank among the greatest discovered in the Mid-Continent field. Less than one-third of the proved acreage has been drilled and the 1928 production will depend primarily on the outlet for moving the oil.

Hendricks Pool, Winkler County.—This pool produces from the "Big Lime" found at depths ranging from 2250 to 2750 ft. Pay horizons are found at depths ranging from 150 to 800 ft. below the top of the lime. The field has developed individual gas wells with a volume of 70,000,000 ft. and individual oil wells with production of more than 900 bbl. per hour.

One well averaging 125 bbl. per day was producing at the beginning of 1927 in the Hendricks pool. The second well was completed the last week in March for an initial daily production of 2580 bbl. This started

an active drilling program, but a shutdown agreement resulted in drilling wells only to the top of the pay. Later it was decided to drill these wells in and pinch their production. In June the production started to climb due to the completion of pipe lines to the railroad loading racks. The average daily production by months is listed below:

	Bbl.		Bbl.
January	122	July	1,203
February	175	August	3,149
March	335	September	8,543
April	1,201	October	12,761
May	905	November	26,961
June	1,231	December	44,981

During the last week in October the field averaged 18,807 bbl. per day from 13 wells, or 1447 bbl. per well. This high well average was increased with the completion of additional wells and during the last week of December, 37 wells, some of which were pinched in, produced an average of 58,976 bbl. per day or 1594 bbl. per well. Water which was found in the west offset to the discovery well in May, 1927, began a rapid encroachment by the last week in December. By the end of the first week in February, 1928, 25 wells were making from 1 to 100 per cent. water. The encroachment of water in December stimulated intensive drilling activity so that on Feb. 3, 1928, there were 51 completed oil wells, 93 drilling operations and 38 rigs and locations. Production had climbed to nearly 100,000 bbl. per day with every indication that it would shortly go much higher.

The discovery area of the field was extended 1½ miles north the last week in July by the Southern Crude Oil Co.'s No. T-88-1 Al, Sec. 44, Block B-26, Public School Lands, a 1000-bbl. producer. It was extended more than a mile southeast early in September by the Murchison-Marland No. 1-A, Sec. 35, Block B-5, Public School Lands, which flowed 195 bbl. per hr. pinched. The following week the field was extended 1¾ miles south by Southern Crude Oil Co.'s No. T-88-1 Bl, Sec. 4, Block 12, Public School Lands, which made more than 5000 bbl. initial. Early in February, 1928, Atlantic Oil Co.'s No. 1-F. Sec. 40, Block B-27, Public School Lands, extended the field 1½ miles northwest, giving a total length of 5¼ miles. A well now drilling by the Amerada Petroleum Corpn. in Sec. 48, Block 26, Public School Lands, is thought to have the "Big Lime" structurally high and at 2404 ft. found 15,000,000 ft. of gas. If this makes a producer it will give the field a probable width of 3¼ miles.

The Hendricks pool is defined by water encroachment on the southwest but its other limits remain to be established. At present it appears that the pool will be much larger than at first indicated; and it may even develop into the largest pool in West Texas.

Movements of oil during January, 1928, averaged 30,132 bbl. per day which was about one-third of the production. Storage is being filled at a rapid rate and unless some relief is afforded it will be necessary to curtail production. Pipe lines now building and announced will give an outlet of 167,000 bbl. early in 1928. The pool is expected to reach that potential figure long before the pipe lines are ready.

Owing to the rapid water encroachment a very active development will take place in 1928 and the field will probably pass its peak within the year.

Summary

In the Panhandle Division four new small producing areas were developed which were not sufficient to halt the decline of the daily average production. Several new discoveries were made, notably in Moore and Gray counties, which may develop into oil fields in 1928. The gas area was further defined and new pipe lines were begun which will make extensive use of the gas reserve. The Panhandle Division will continue to be a major field in 1928, but will not produce as much oil as in 1927 unless the market improves enough to stimulate prospecting.

Three discoveries of 1926, Church-McElroy, Yates, and Hendricks, were developed into major pools of high initial production in 1927, one of which (Hendricks) is still largely undefined. Two discoveries, Gulf Production Co. Waddell No. 2, Crane County, and Llano Oil Co. Scarborough No. 1, Winkler County, were made which may develop into major pools. Several of the old fields were revived by extensions, notably McCamey. Deeper production is indicated both in the "Big Lime" and below the "Big Lime." The price of West Texas crude was reduced in August to a figure which requires gusher production in order to operate at a profit. This reduction in price has not seriously retarded prospecting or the development of the pools.

West Texas gross production will be limited only by the ability to handle the oil. At its present daily average it would produce 100,000,000 bbl. of oil in 1928 and with adequate outlets could exceed this figure. Two pools, Yates and Hendricks, hold the key to the situation. They have a combined proved territory in excess of 20,000 acres within which many locations remain to be drilled. Prospects are good for the opening of other pools in territory which may necessitate competitive drilling and, therefore, result in a rapid increase of the daily average production. Present indications are that West Texas will continue the dominant factor in the industry of the state for the current year; and it may conceivably dominate the entire Mid-Continent as well.

Petroleum Development in East Texas and along the Balcones Fault Zone, 1927

By R. A. Liddle,* Fort Worth, Texas

(New York Meeting, February, 1928)

Intermittently during the past 10 years showings of oil and gas in tests drilled in the eastern part of Texas have stimulated the search for production. Tests on the flanks of the long-known salt domes, principally Keechi and Butler, have found oil in small quantity in the Woodbine formation of the basal part of the Upper Cretaceous. In the central part of Cherokee County, Colliton et al, in 1926, in their Clapp No. 2 found a good showing of 37° Bé. oil at about 3500 ft. Several wells were drilled in 1926 and 1927 as a result of this showing. On Jan. 22, 1927, Humble Oil & Refining Co. wildcatting on Carey Lake salt dome, obtained commercial production in its Clark No. 1. This inaugurated intensive exploration both for salt domes and for other types of structure. As a result several new domes and a few promising structures of other types have been discovered.

Development in East Texas during 1927

Carey Lake Dome

Location.—On the Neches River in Anderson and Cherokee counties, 10 miles west of Jacksonville, Cherokee County. (Fig. 1.)

Date of Discovery.—During 1925 geologists of the Humble Oil & Refining Co. working in the Neches River valley discovered slight surface fractures, erratic dips, and slickensided clays and sands in greensands of the Mount Selman formation north of Carey Lake. A number of core tests were drilled by the Humble Oil & Refining Co. during 1925 and 1926, some more than 1500 ft. deep, to check their surface observations of faulting, and the possibilities of a salt dome. On May 16, 1927, solid rock salt was reached at 2142 ft. in the first deep test on the prospect.

Surface Indications.—Surface indications of the Carey Lake dome, though not as evident as manifestations at the previously known domes of Palestine, Keechi, Butler, Grand Saline, Steen and Brooks, are more noticeable than on any of the domes discovered in 1927. F. E. Poulsen, of the Pure Oil Co., who examined the area before the deep tests were drilled, noted the alignment of erratic surface dips which suggested faulting, especially in conjunction with slickensiding, and the local deflec-

* Geologist, Pure Oil Co.

tion of the course of the Neches River. Boggy Creek to the south, Carey Lake and a fairly large open prairie to the east and southeast were also considered to be earmarks of a dome.

Depth to Salt.—Several wells drilled on this dome have encountered rock salt, but the shallowest known depth at which it was reached is 2142 ft. This well is located at the southwestern end of the salt mass, and it is probable that on top of the dome salt may be nearer the surface.

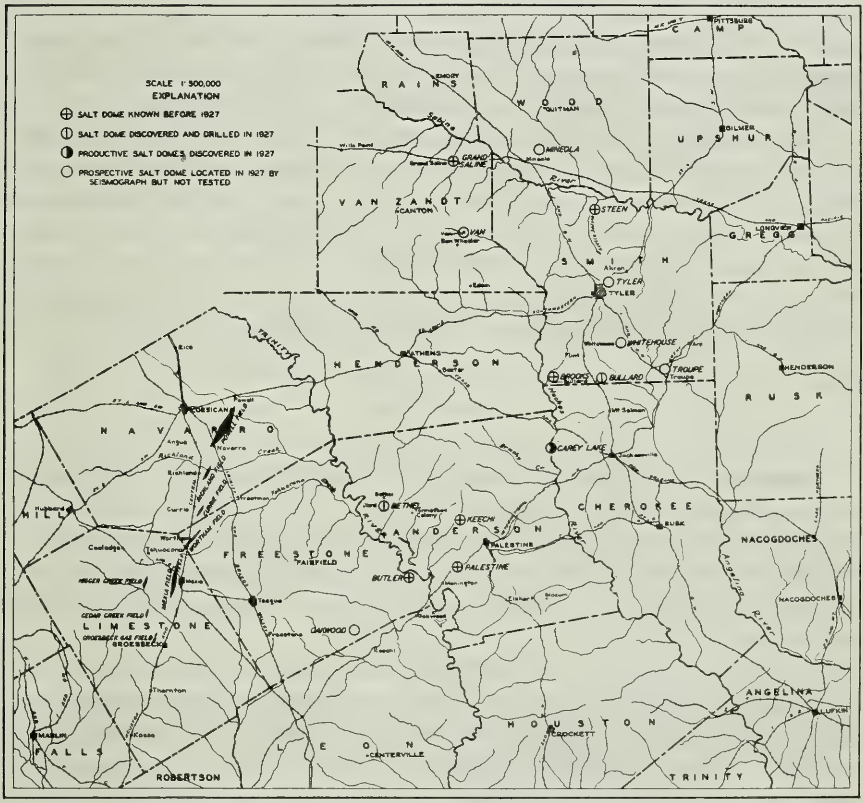


FIG. 1.—SALT DOMES IN EAST TEXAS OIL FIELDS ON THE MEXIA FAULT ZONE.

Development.—All deep drilling on this dome has been done by the Humble Oil & Refining Co. Its Spencer Clemmons No. 1 reached salt on May 16, 1927. A location was then made on the J. A. Templeton farm at the northeastern side of the dome, but a later location on the Clark farm at the southeastern end of the dome was completed first. On Jan. 22, 1927, an oil-saturated sand was reached in Clark No. 1 at 3841 ft. and it was cored to 3849 ft. The well was tested at this depth and averaged 50 bbl. an hour through a $\frac{1}{4}$-in. choke. Nine deep tests

have been drilled on this dome, but production has been obtained from only two wells.

Age of Producing Horizon.—The producing horizon is considered to be in the Bingen formation, an eastern equivalent of the Woodbine and Eagleford formations, of the lower part of the Upper Cretaceous.

Production.—The Humble Oil & Refining Co. Clark No. 1, after several tests, was rated as a 2000-bbl. well. The oil is 38.6° Bé. An average of 750,000 cu. ft. of gas at 490 lb. rock pressure was gaged. It was shut in for storage and on May 3, 1927, when opened again it showed water. The water rapidly increased and during the rest of the year it made only a small amount of oil. Clark No. 2, completed Nov. 14, 1927, now shut in, is estimated at 5,500,000 cu. ft. of wet gas.

The history of this discovery is similar to a discovery by the same company on the Piedras Pintas salt dome in Duval County in December, 1925. The discovery of oil in commercial quantity on an inland dome in east Texas stimulated much activity. Additional leases were taken on previously known domes—Palestine, Keechi, Butler, Grand Saline, Steen, and Brooks—and many companies commenced an extensive examination with seismograph of the inland dome area.

Bethel Dome

Location.—In Anderson County, 20 miles northwest of Palestine and 2 miles south of the village of Bethel.

Date of Discovery.—Discovered by a seismograph party of the Geophysical Research Corpn. in the employ of the Pure Oil Co., on April 21, 1927. On Nov. 18, 1927, rock salt was encountered in the first test drilled.

Surface Indications.—In the latter part of March, 1927, the geological department of the pure Oil Co. while examining the northwestern part of Anderson County for surface manifestations of salt domes found seepages of gas in marshy areas along Catfish Creek. On account of alluvium in the lowlands, and lack of key beds in the Wilcox formation on the hills to the east it is impossible to determine at the surface if there is local uplift. It was thought that the surface evidence warranted examination by seismograph, and on April 21, 1927, it was shot by a geophone crew of the Geophysical Research Corpn., and a dome was discovered. Shortly afterward it was checked by the Gulf Production Co.

Depth to Salt.—The depth to the salt calculated from seismograph data was 1500 ft. and later Cook No. 1, located at the south edge of the salt mass, encountered rock salt at 1600 ft. It is probable that salt on the top of the dome will be as shallow as 1500 ft., or possibly less.

Development.—The majority of the acreage was blocked jointly by the Pure Oil Co., Gulf Production Co., and Humble Oil & Refining Co., and a joint well was drilled at the south edge of the top of the dome.

Samples from the first 1300 ft. are typical soft sandstone and lignitic shale of the Wilcox formation of the Eocene. Between 1300 and 1380 ft. the sandstones are more calcareous and there is a small amount of greensand, but no fossils were found. At 1380 ft. the sandstone becomes decidedly calcareous and glauconitic, and contains an abundant microfauna which is thought to be Midway in age. Calcite veins cut the sandstone and this mineral increases to 1445 ft. where it is present in large amounts. The material below 1380 ft. is extremely crumpled, full of stress planes, highly fractured and saturated with asphaltic oil. At 1465 ft. returns were lost in caprock of nearly pure anhydrite which continues to 1600 ft. where pure rock salt was cored. The well was abandoned at 1610 ft.

Bullard Dome

Location.—Smith County, in the east-central part of the Vinson Moore survey, 2 miles northeast of the town of Bullard.

Date of Discovery.—April, 1927, by a seismograph party of the Gulf Production Co.

Depth to Salt.—Calculated depth from seismograph records 500 ft. Gulf Production Co., Morgan No. 1, encountered anhydrite at 382 ft. and solid rock salt at 527 ft.

Development.—The Gulf Production Co. Morgan No. 1, commenced Oct. 24, 1927 and abandoned at 527 ft. in rock salt, is the only well which has been drilled.

Tyler Prospect

Location.—Smith County, 1 mile northeast of the town of Tyler.

Date of Discovery.—July, 1927, by a seismograph party of the Humble Oil & Refining Co.

Depth to Salt.—Calculated depth from seismograph records $\pm$ 800 ft.

Development.—There has been no drilling on this prospective salt dome.

Whitehouse Prospect

Location.—Smith County, 3 miles northeast of Whitehouse.

Date of Discovery.—April, 1927, by a seismograph party of the Humble Oil & Refining Co.

Depth to Salt.—Calculated depth from seismograph records $\pm$ 500 ft.

Development.—There has been no drilling on this prospective salt dome.

Mineola Prospect

Location.—Wood County in the Wesley Tollet survey, 5 miles northeast of Mineola.

Date of Discovery.—June, 1927, by a seismograph party of the Gulf Production Co.

Depth to Salt.—Calculated depth from seismograph records ± 500 ft.

Development.—There has been no drilling on this prospective salt dome.

Troupe Prospect

Location.—Smith County, 2 miles east of north from Troupe.

Date of Discovery.—June, 1927, by a seismograph party of the Amerada Petroleum Corpn.

Depth to Salt.—So far as known, no salt records were obtained at this prospect, but there is a distinct uplift which has been isolated. The location of this local uplift—well down in the regional syncline of east Texas—strongly suggests that it is due to a deeply buried dome. The inability to identify salt records may be due to the similarity of rate of speed for seismograph waves in salt and in hard chalk or limestone which is probably present about 3500 ft. below the surface.

Development.—There has been no drilling on this prospect.

Van Prospect

Location.—Van Zandt County, at the town of Van.

Date of Discovery.—May, 1927, by a seismograph party of the Geophysical Research Corpn., in the employ of the Pure Oil Co.

Depth to Salt.—No salt records were obtained at this prospect, but there is definite uplift which has been isolated. Its character from seismograph work appears similar to the uplift at Troupe, and its location in respect to regional structural features in east Texas suggests a deeply buried dome.

Development.—There has been no drilling on this prospect.

Oakwood Prospect

Location.—Freestone County, 10 miles southwest of Oakwood and 5 miles northwest of Keechi in Leon County. This is called the Oakwood prospect, because the name Keechi has been applied to an old dome in Keechi Creek in Anderson County.

Date of Discovery.—September, 1927, by a seismograph party of the Roxana Petroleum Corpn.

Depth to Salt.—It is reported that the depth to the salt calculated from seismograph data is about 800 ft., but it is not known if this has been confirmed.

Development.—In the latter part of November, 1927, the Roxana Petroleum Corpn. commenced a well which is east of the prospect. It has been drilled to 4037 ft., but neither salt nor anhydrite has been reported.

Development along Balcones Fault Zone during 1927

Along the Balcones fault zone during the past year the old fields have steadily declined and for the most part exploration for new fields has been disappointing. The only new production from the Woodbine, excepting a local Kollman sand production in Mexia field, has been obtained from Cedar Creek field. Wildcatting for oil in serpentine plugs resulted in the discovery of the Dale field, Caldwell County, which to date has produced only a small amount. Showings in the Glenrose formation of the Lower Cretaceous have been found, but Chittim No. 1 of the Rycade Oil Corpn. in Maverick County, which tested 28,400,000 cu. ft. of gas and 100 bbl. of 56° Bé. distillate is the most important discovery.

Exploration in Comanchean and Older Rocks

Search for production along the Balcones fault zone in the Lower Cretaceous and older beds has resulted in the drilling of five deep tests at widely separated localities. Though the tests listed below were commenced before 1927, all of them were active during 1927, and for this reason they are mentioned:

Swink No. 1-C, of the Sun Oil Co., in the Richland field, Navarro County, Texas.

Stubenrauch No. 1, of E. L. Smith et al, in the Mexia field, Limestone County, Texas.

Bassett No. 1, of the Pandem Oil Corpn., 3 miles northwest of Kosse, Limestone County, Texas.

Kelley No. 1, of the United North and South, in the Luling field, Caldwell County, Texas.

Tiller No. 2, of the United North and South Co. in the Luling field, Caldwell County, Texas.

Chittim No. 1, of the Rycade Oil Corpn., Chittim Ranch, Maverick County, Texas.

Chittim No. 2, of the Rycade Oil Corpn., Chittim Ranch, Maverick County, Texas.

Sullivan No. 1, of the Rycade Oil Corpn., Sullivan Ranch, Maverick County, Texas.

The Sun Oil Co. Swink No. 1-C was commenced on Aug. 20, 1926, and reached a depth of 5415 ft. on March 3, 1927. It was reported to have entered the top of the Woodbine at 3469 ft. From 5174 to 5186

ft. it bailed 5 bbl. of light oil from sandy limestone. At 5187 ft. a small amount of salt water began to show. Deeper drilling increased the water and the test was abandoned in the Glenrose limestone.

E. L. Smith et al., Stubenrauch No. 1 commenced drilling on Oct. 28, 1926, and reached its present depth of 5753 ft. on May 26, 1927. A slight show of low gravity oil was encountered from 4192 to 4196 ft. in sandy limestone, and at 5753 ft. an initial estimated flow of 3,000,000 cu. ft. of gas and about 20 bbl. of fluid, less than 5 of which were 39° Bé. oil. The volume of gas rapidly decreased as did the fluid until at present it makes 1 to 2 bbl. of oil a day and 1 to 10 bbl. of salt water. This production is from the Glenrose limestone.

Pandem Oil Co. Bassett No. 1, in the J. Walker Survey 3 miles west of Kosse, Limestone County, was commenced Aug. 20, 1926, and was abandoned in Glenrose limestone Oct. 7, 1927, at 6045 feet.

Examination of samples of the Lower Cretaceous from Swink No. 1-C, Stubenrauch No. 1, Bassett No. 1, and a comparison of this material with cuttings from Betty Robertson No. 1, West Berthelson No. 1, and Mary Focke No. 1 of the Pure Oil Co., in the Mexia field and on the North Groesbeck structure, reveal interesting faunal zones, some of which have been identified at localities where the Comanchean outcrops. In the Comanche Peak there is a definite zone of abundant *Tritaxia* sps. In the lower part of the Fredericksburg there is a distinct zone of *Orbitolina* sps., and in the Glenrose so far as penetrated in the deepest wells two Orbitoid zones have appeared. Local structural features indicated by these correlations are extremely interesting, as it may be necessary to modify general conceptions of structure in deeper beds along the Balcones fault zone.

The United North and South Co. during 1927 continued to deepen its Kelly No. 1 and Tiller No. 1 at the northwest side of the Luling field. At 4700 ft. in Kelly No. 1 schist was encountered, and the well is still drilling in this material at 7442 ft. In Tiller No. 1 schist was reached at about the same depth as in Kelly No. 1, and the well is still drilling in this material at 6929 feet.

On the Chittim Ranch in Maverick County the Rycade Oil Corpn. commenced its Chittim No. 1, in July, 1925, and on Nov. 11, 1926, it encountered at 5515 ft., 5,000,000 cu. ft. of wet gas in the Glenrose formation of the Lower Cretaceous. The main gas horizon which tested 28,400,000 cu. ft. of wet gas and produced 100 bbl. of 56° Bé. distillate a day was not reached until April 29, 1927, at a depth of 5590 ft. After considerable mechanical difficulty the well is standing at 5630 ft., in limestone of the Glenrose formation.

Chittim No. 2 was commenced Aug. 22, 1927, encountered a showing of about 1 bbl. of 17° Bé. oil in the Eagleford between 2410 and 2460 ft., and was drilling Jan. 11, 1928, in Del Rio clay at 2819 ft. The top of this formation is reported to be at 2610 feet.

These wells are on a large southeast plunging nose which has a marked influence on the local strike of contacts of surface formations.

Sullivan No. 1, 5 miles northwest of Chittim No. 1, has a hole full of salt water in the Glenrose formation at 5510 ft.

New Production from Serpentine in the Upper Cretaceous

Dale Field

Discovery of oil in serpentine in the Lytton Spring field in Caldwell County in March, 1925, resulted in an extensive campaign in Caldwell and adjoining counties for the location of similar serpentine masses. A great number of wells were drilled, and in several, serpentine was encountered.

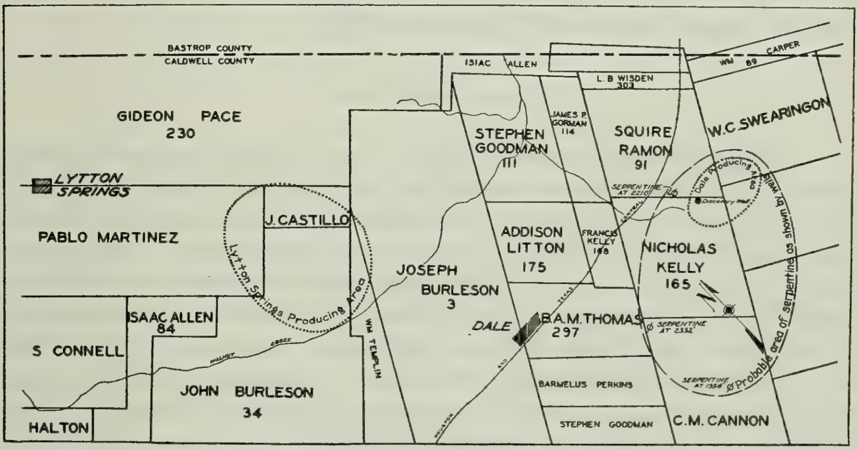


FIG. 2.—DALE FIELD, CALDWELL COUNTY, TEXAS.

Showings of oil were reported in a few tests, but the first commercial producer was Beaty No. 1 of the Texas Co. et al., which opened the Dale field (Fig. 2), 4 miles northeast of Lytton Spring field in Caldwell County. In the discovery well, commenced June 17, 1927, serpentine was reached at 2121 ft. and was penetrated to 2323 ft. where it initially pumped 100 bbl. Although most of the wells in the field were small a few were of interesting size. Beaty No. 2 flowed 608 bbl. the first 24 hr. and 614 bbl. the second 24 hr. The initial decline of these wells is rapid. To date there are 13 producing wells in the field which is at the northeastern end of the serpentine plug. About 15 dry holes have been drilled in the Dale field. The total daily production of the field is about 420 bbl. No production has been obtained at any other locality on the plug, but the remainder of the area in which serpentine is known is not entirely condemned as only a few wells have been drilled. However,

much of the serpentine is not porous and the mass is considerably faulted. In the Dale field, as at Lytton Spring, the main body of the serpentine is in the horizon of the Austin chalk and the lower part of the Taylor formation.

Adams Gas Field

Activity has continued during 1927 in the Adams gas field in the southeastern part of Medina County, where wells averaging 15,000,000 cu. ft. at 475 lb. rock pressure are being reached between 900 and 1000 ft. in the Escondido formation of the uppermost part of the Upper Cretaceous. The surface structure of the producing field is an anticline bounded on the north by a small fault, downthrown to the north. To the southwest of the field there is a less definite surface structure whose position suggests an *en échelon* arrangement.

Cedar Creek Field

Commercial production in Nigger Creek field, Limestone County, Texas, proved that, in this part of the Balcones fault zone, faults with upthrown side to the southeast and proper closure would produce oil and gas, though their location was west of producing fields. Before this discovery it was not known if there was sufficient drainage to fill the so-called "back" structures. This information stimulated the testing of the Cedar Creek fault 2 miles southeast of Nigger Creek field. W. A. Reiter et al. commenced drilling R. P. Ward No. 1, the discovery well, on June 28, 1927. On Aug. 16, 1927, an oil-saturated sand was cored from 2888 to 2896 ft. The well came in making 9,357,000 cu. ft. of gas and 145 bbl. of 35° Bé. oil. The production of this well reached as high as 206 bbl. on Sept. 3, 1927, after which water began to show. Several wells were drilled in the immediate vicinity but only small production was encountered. The daily average production for the field during December, 1927, was 829 bbl. from 11 wells. The total production for the field during 1927 was 86,285 barrels.

Decline of Production in Main Old Fault Line Fields

There has been but little drilling during 1927 within the proved fields of Powell, Richland, Currie, Wortham and Mexia, and consequently there has been a steady decline of production. Locally in the western part of the Mexia field small production has been secured from the so-called Kollman sand, a lower member in the Woodbine formation. The following tabulation gives the comparative production in the fault line fields for 1926 and 1927:

Production in Fault Line Fields, 1926 and 1927

Field	1926, Bbl.	1927, Bbl.
Powell	10,022,424	5,839,109
Richland, Currie	853,951	573,423
Wortham	2,711,123	1,134,492
Mexia	4,398,585	3,622,494
Nigger Creek	1,585,470	972,280
Luling	7,779,915	6,002,060
Lytton Spring	1,758,315	742,645

Oil Production and Development in North Central Texas during 1927*

By W. G. Wender,† Cisco, Texas

(New York Meeting, February, 1928)

The North Central Texas district, as known to the oil fraternity, is the area producing from sands and limes of Pennsylvanian age, roughly embracing the territory lying between Fort Worth and Abilene in an east-west line, and between the Red River and the Llano Mountains in a north-south line. The history of oil development in North Central Texas during the year 1927 is briefly reviewed in the following paragraphs.

Brown County

New discoveries and development in Brown County centered mainly around the Fry pool, located in the west central portion of the county. Important discoveries for the year were:

Shoupe No. 1 John Byler, discovery well of the Byler pool, located 2 miles south of the Fry pool which came in early in February, 1927, at 1262 ft. for 90 bbl. in the Fry sand of upper Strawn (Pennsylvanian) age.

Rosenfield No. 1 P. Davis, discovery well of the Smith-Ellis pool located 1½ miles northeast of the Fry pool, came in March 7, in the Fry sand from 1277 to 1279 ft. for 30 bbl. initial.

Pandem Oil Corpn. No. 1 Mrs. T. Hutton, located 1 mile east of the Smith-Ellis pool, came in in December in the Fry sand from 1119 to 1130 ft. for 45 barrels.

The Fry pool passed its daily production peak of 25,000 bbl. during the first part of June, and declined to a daily production of 5100 bbl. by the close of the year. The oil recovery from the Fry pool up to Jan. 1, 1928, slightly exceeded 4,000,000 bbl., averaging 4700 bbl. to the acre over the entire pool. The Smith-Ellis pool passed its daily production peak of 8300 bbl. in October, 1927, and dropped to 3600 bbl. by the close of the year. The possibilities of the Byler pool will be unknown until the area is fully drilled up. In the Blake pool, production passed 2,500,000 bbl. for the year. The per acre recovery in this pool up to Dec. 31, averaged slightly over 5000 barrels.

---

* Published by permission of Amerada Petroleum Corpn.

† Geologist, Amerada Petroleum Corpn.

Callahan County

An interesting discovery in Callahan County was made by the Empire Gas & Fuel Co. on the W. Johnson Ranch located in the northeast corner of Sec. 146, G. H. & H. R. R. Survey, South Callahan County. In March this well came in making 9,000,000 cu. ft. of dry gas at 4060 ft., and when deepened in June made an oil well in an horizon correlated as Ellenberger limestone (Ordovician) by some geologists. After producing better than 2 months and recovering 35,000 bbl. of oil it was drowned out by water intrusion. Other development in Callahan County was confined to redrilling and extension of old pools. Repressuring of shallow sands is being tried out in some of the pools of northeast Callahan County.

Coleman County

Interest in Coleman County centered around the Chestnut & Smith and Eastland Oil Co. No. 2 Morris, located in the John Webber Survey, 6 miles northeast of Coleman. This well came in Dec. 15 for 400 bbl. of 41° Bé. oil at 2100 ft. in the Fry sand horizon. The No. 2 Morris well was drilled on evidence of a show encountered in their No. 1 Morris which was completed earlier in the year.

Two other wells opened up possible commercially productive areas in Coleman County. Cheney-Continental Oil Co. No. 1-C, T. Overall, located 7 miles southwest of Coleman came in the first week of October for 50 bbl. in an Upper Canyon (Pennsylvanian) sand from 1605 to 1610 feet.

Ross Drilling Co. No. 1 J. Brenecke, S. Sprague Survey 1 mile northwest of Santa Anna came in the first week in December for 30 bbl. in a sand encountered from 1830 to 1834 ft. This well has been producing to date without being drilled through the sand and should make a better showing upon being deepened.

Clay County

Interest in Clay County centered around the Petrolia field where the Western Oil Corpn. has been experimenting with repressuring of shallow sands on old leases. They have been able to substantially increase production.

Cooke County

This county had a very active year during 1927. In the Bulcher area of northwest Cooke County three new sands were discovered below the original 1250-ft. horizon discovered on June 30, 1926.

Depth of Producing Horizon, Ft.	Company	Farm	Date of Discovery	Initial Production, Bbl.
1310 to 1318	Chapman-Lanier	No. 1 Montgomery	4/1/27	126
1403½ to 1408	Pure Oil Co.	No. 1 Embry	6/6/27	400
1751 to 1753	Danciger Oil	No. 1 Harris	6/6/27	

In the Muenster pool a deeper sand at 1600 ft., was discovered by the Oil Operators Trust Co. in No. 2 Kleiss-"A" which made 350 bbl. of 31° Bé. oil on April 1. This lower sand has proved a prolific horizon.

Other discoveries in Cooke County were as follows:

On Sept. 24, Lynch-Stahl and Burress No. 1 Danglemeier located 1 mile north of Muenster opened a small shallow pool of 35° Bé. oil in a sand encountered at 800 feet.

On April 1, Fain-McGaha Oil Corpn. No. 1 Otto located 3 miles northeast of Muenster opened another shallow pool in a sand encountered at 860 feet.

Production in Cooke County is found in sand lenses, of Canyon and Cisco age, which pinch out on the flanks of old Ellenberger limestone ridges, traversing the county in a northwest-southeast direction. The gravity of the oil ranges from 30° to 40° Bé., and is very similar to other North Central Texas crudes.

Future possibilities for extensive development in Cooke County look very encouraging.

Eastland County

No major pool was discovered in Eastland County during 1927. Thomas & Reynolds et al. No. 1 McAllister opened a new lime pool in central Eastland County, which proved to be a disappointment. The Ramsower 3800-ft. lime pool of north Eastland County, discovered in 1926, has proved to be much better. Production in this pool is holding up very satisfactorily.

The average per acre recovery for Eastland County lime production up to Dec. 31, 1927, was approximately 2000 bbl. The average daily income per well for 1927 was $12.75 from oil, and $11.00 from casinghead gasoline.

Jack County

This county saw considerable development in the Bland & Strange 500-ft. Cisco sand pool of northwest Jack County. Considerable development also took place in the Leidecker northwest extension of the Buttram pool, located in the southwest part of the county. This pool produces from the Upper part of the Strawn Group.

MONTAGUE COUNTY

Due to the low price of low gravity oil during 1927 there was very little wildcat development in this county. Drilling was confined mainly to the Nocona pool.

SHACKELFORE COUNTY

The very extensive wildcat play inaugurated by the Cook pool discovery in this county was very disappointing. Approximately 180 wildcats drilled in the west half of Shackelford county opened but one field of importance. This new discovery was Simmons et al No. 1 Harvey, located in Sec. 6, Block 14, T. P. R. R. Survey, western Shackelford County, which produces from 1600 ft. In November Cowboy Evans et al. No. 1 King, a 50-bbl. well, extended this pool one-half mile north.

The Cook pool was partially closed in during most of the year due to the low price of high gravity crude. At the close of 1927 its oil production exceeded 3,100,000 bbl. giving an approximate recovery of 5000 bbl. per acre from date of discovery, Feb. 16, 1926, to Jan. 1, 1928. Its maximum daily production for 1926 and 1927 was 10,859 bbl., reached on Feb. 4, 1927.

Development in the shallow sand area of northeast Shackelford County was quite active during 1927. Considerable new production was obtained.

THROCKMORTON COUNTY

The results of deep drilling around the Woodson area of this county were discouraging. The remainder of the county was inactive during the year.

WILBARGER COUNTY

Activity in this county centered around the Fluhman pool, located west of the South Vernon pool, and around the Texas Co., B-1 Waggoner, located in the northwest quarter of Sec. 17, Block 4, H. & T. C. Survey, which came in Oct. 31, 1927, at 2400 ft. for 400 bbl. initial. This producer extended development 3 miles southeast of the Rock Creek Crossing pool.

FOARD COUNTY

Another important 1927 discovery was made on the South Vernon-Fluhman trend by the Roxana and Fain-McGaha Corpn. on the F. J. Matthews farm, located in Sec. 3, G. C. & S. F. Survey, northeast Foard County.

This well had gas sands at 855 ft., 1379 ft., 1668 ft., and an oil and gas sand at a depth of 1454 ft., which produced better than 50 bbl. the first

2 days. It went into metamorphosed beds at 2180 ft., and drilled to 2550 ft. It was plugged back and completed in the gas sand at 855 feet.

Wichita and Archer Counties

No outstanding new discoveries were made in Wichita and Archer counties. Development was mainly confined to drilling up leases in the Turberville pool and in the redrilling and deepening of old wells.

Young County

The major development in this county took place in the Graham pool, 2100-ft. Strawn production, and in the South Bend pool 3900 and 4200-ft. horizons of Bend (Pennsylvanian) age. The South Bend deep (4200-ft.) production was opened by E. C. Stovall on fee land, Dec. 25, 1926. An outstanding well in this pool was the Panhandle Oil & Refining Co. No. 7 McCleskey, which averaged better than 4000 bbl. daily for 60 days.

Sinclair Oil & Gas Co. No. 1 Moran produced 663,421 bbl. of oil between March 17, 1923, and Jan. 1, 1928, valued at $1,100,000. During this time its daily average production was 323 bbl. During the latter part of 1927 the well's production dropped to 50 bbl. However, the daily production of the well went up to 425 bbl. per day after cleaning out.

Conclusion

Despite curtailed wildcat drilling and partially shut-in production, the North-Central Texas area had 23 proved and potential discoveries in 1927. The limits of proved oil territory were considerably extended. Increase in production for 1928 is very probable. The opening of shut-in production and drilling undeveloped proved acreage alone should be sufficient to maintain the production figure of 1927. If market conditions improve during 1928, activity and development in North-Central Texas should surpass previous records.

DISCUSSION

J. M. Lovejoy,* Tulsa, Okla.—This area is one of the few districts in the Mid-Continent field where it is possible to make a profit today by producing oil. The oil is of very high grade and the cost of drilling is small. Of course, to offset that, it is a very spotty area and there are many places where you get encouraging results which cause you to drill more wells which do not come out right. On the other hand, the pools such as Fry pool and the Cook pool in Shackelford County and the Cowboy Evans pool have been exceedingly profitable and are now probably in proportion to their size the most profitable spots in the entire Mid-Continent-field.

* Vice-president, Amerada Petroleum Corpn.

Review of the California Oil Industry in 1927

By Earl W. Wagy,* San Francisco, Cal.

(New York Meeting, February, 1928)

The year 1927 witnessed numerous developments of significance in California. The State's shut-in production increased from an average of 58,000 bbl. daily in January to a maximum of 93,000 bbl. daily in August, and a total of about 25,000,000 bbl. was withheld from the market during the year. This not only lessened the effect of large production at Huntington Beach, Seal Beach and Alamitos Heights, but also was a most effective conservation move. Since 1922, it is estimated that approximately 100,000,000 bbl. of oil that would otherwise have been produced have been held in the ground.

I. Outstanding Field Developments of 1927[1]

1. Long Beach Deep Sand.
2. Rincon (Seacliff)Discovery.
3. Alamitos Heights Discovery.
4. Ventura Avenue Extension.
5. Round Mountain Discovery.
6. Mt. Poso Extension.
7. Potrero (Cypress) Discovery.
8. Buttonwillow Gas Development.
9. Goleta Discovery.
10. Union Avenue, Edison and Fruitvale Areas. (See Fig. 1.)

II. Crude Production

The most important factor in new crude production in 1927 was the Seal Beach field with its adjacent Alamitos Heights townlot area. Production increased from about 10,000 bbl. daily in January, to a peak of 66,000 bbl. in June. Huntington Beach finished the year 1926 with a production of 102,000 bbl. daily, which declined to 60,000 bbl. by the end of 1927. Due to production in these three areas and the tempering effect of shutting in numerous wells, the California production curve for 1927 was held at a fairly even level. Fig. 2, shows the State's production in 1927 and 1926 as compared with 1923, which was the year of excessive

---

* Petroleum Engineer, Standard Oil Co. (California).

[1] Discussed in detail under Section VII.

flush production in California, due principally to the townlot fields of Long Beach, Santa Fe Springs and Huntington Beach. The output of 230,751,463 bbl., or 632,196 bbl. daily, in 1927 was greater than for any other year except 1923. Table 1 shows the production by fields.

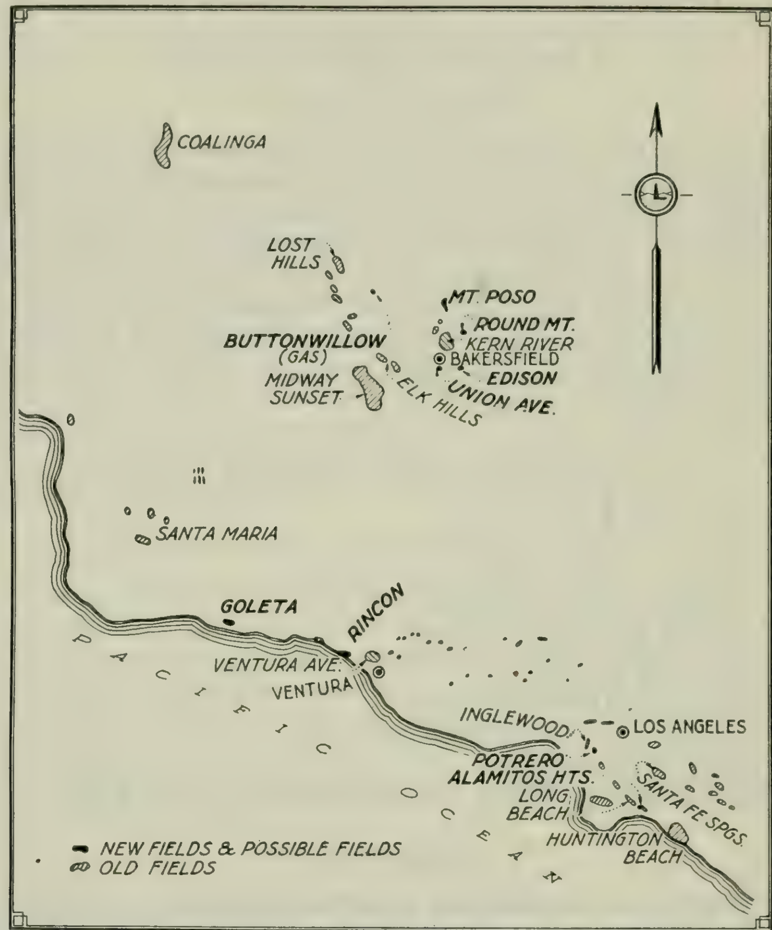


FIG. 1.—CALIFORNIA OIL FIELDS, OLD, NEW AND PROSPECTIVE.

III. STOCKS

Stocks of light crude showed a net decline of 10,550,000 bbl. for the year, heavy crude and fuel oil increasing 4,300,000 bbl. (Fig. 3). Stocks of all petroleum products totaled approximately 137,400,000 bbl. at the end of the year, a decline of 8,200,000 bbl. as compared with a decline of about 3,500,000 bbl.[2] in 1926. As a result of the heavy draft on light

[2] This figure does not include 8,200,000 bbl. fire loss.

oil stocks which were used, for the most part, to make gasoline, the stocks of gasoline increased 1,050,000 barrels.

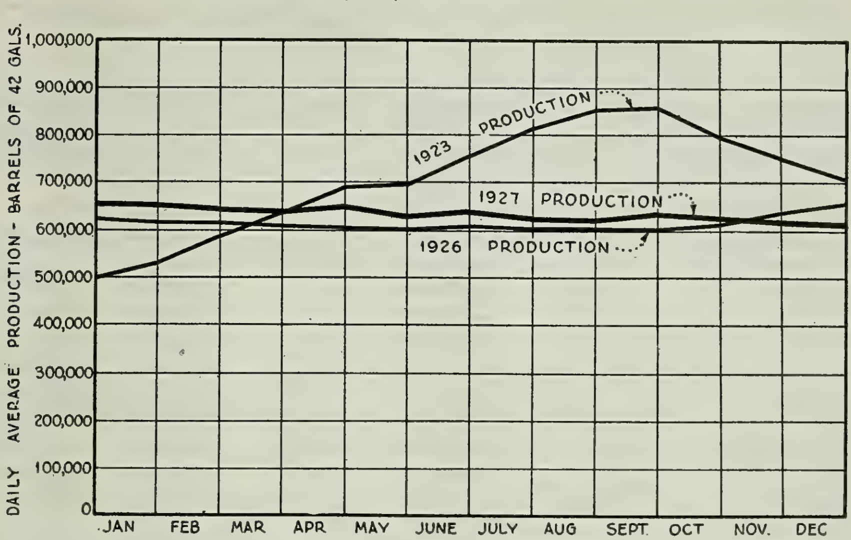


FIG. 2.—CALIFORNIA PRODUCTION IN 1926 AND 1927 AS COMPARED WITH 1923.

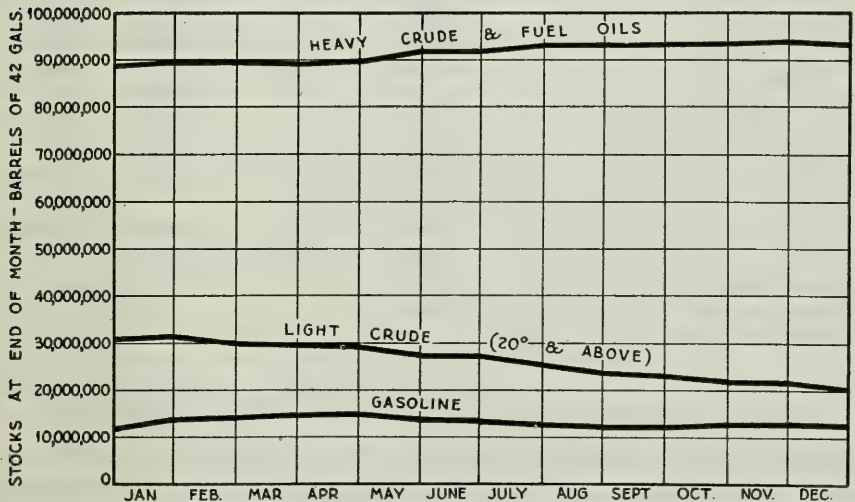


FIG. 3.—STOCKS OF LIGHT AND HEAVY CRUDE AND GASOLINE FOR 1927.

IV. DEMAND

The total demand for petroleum products is estimated to have averaged 687,000 bbl. daily in 1927, as compared with 649,000 in 1926, a gain of 6 per cent. The domestic gasoline demand in the California district[3]

[3] Seven western states, Alaska and Hawaii.

TABLE 1.—*Total Yearly Production by Fields*
(Bbl. of 42 Gal.)

	1927	1927 Per Cent. of Total	1926	1923
Long Beach	34,541,667	14.97	37,931,964	68,810,361
Midway-Sunset	31,670,708	13.73	33,968,755	27,803,281
Huntington Beach	26,344,697	11.42	19,064,814	34,355,642
Ventura Ave	17,808,704	7.72	14,795,495	
Seal Beach	16,424,929	7.12	587,107	
Santa Fe Springs	15,153,578	6.57	17,446,709	79,781,275
Inglewood	12,751,556	5.53	17,390,131	
Elk Hills	10,073,073	4.37	12,292,754	8,174,371
Torrance	8,338,938	3.61	10,354,905	3,128,694
Richfield	7,884,042	3.42	5,574,244	6,121,335
Coalinga	7,154,599	3.10	7,295,807	5,210,839
Fullerton	7,008,934	3.04	6,987,489	4,064,661
Kern River	6,098,582	2.64	4,358,396	6,816,134
Dominguez	5,887,645	2.55	7,801,586	157,698
Montebello	5,498,252	2.38	6,515,493	4,075,669
Coyote	5,146,864	2.23	6,030,619	2,447,825
Rosecrans	3,506,116	1.52	6,114,430	
Ventura Co.-Newhall	2,197,644	0.95	2,204,381	3,702,404
Santa Maria	1,999,051	0.86	1,852,356	3,003,672
McKittrick	1,855,603	0.80	1,961,028	2,191,702
Lost Hills-Belridge	1,515,300	0.66	1,693,666	1,843,483
Whittier	660,505	0.29	746,125	645,219
Los Angeles-Salt Lake	630,600	0.27	675,950	1,192,036
Wheeler Ridge	374,734	0.16	371,981	128,674
Goleta	86,840	0.04		
Summerland	49,475	0.02	46,865	52,862
Mt. Poso	40,277	0.02		
Watsonville	20,871	0.01	20,990	21,058
Newport	12,485	0.01	32,973	
Round Mountain	8,700			
Rincon (Seacliff)	5,923			
Potrero (Cypress)	571			
Totals	230,751,463	100.00	224,117,013	263,728,895

increased over 13 per cent. over that of the previous year, averaging over 100,000 bbl. daily in 1927. Pacific export markets consumed 13,000 bbl. of gasoline daily, an increase of 19 per cent., the Australian and New Zealand markets absorbing nearly half of these exports. Panama Canal shipments of gasoline amounted to 48,000 bbl. daily.

V. TRANSPORTATION AND REFINING

There was little pipe line development during 1927. A gas line was constructed from the Ventura Avenue field to Los Angeles and several

short lines were laid out of the Seal Beach and Alamitos Heights areas to care for the new production of these fields.

California refineries increased their output of gasoline to 167,000 bbl. daily in 1927, an increase of 21 per cent. One new refinery of 13,000 bbl. capacity was constructed at Dominguez in southern California. A number of refiners installed cracking stills, but according to monthly statements from the U. S. Bureau of Mines, the amount of cracking on the Pacific Coast is still far behind that in the rest of the country. It is estimated that almost 10,000 bbl. daily of cracked gasoline were produced in 1927, as compared with some 270,000 bbl. daily in the eastern areas.

VI. Prices

Prices on the Coast were at low levels during most of 1927, due more or less to the poor national situation in the industry. Except for several

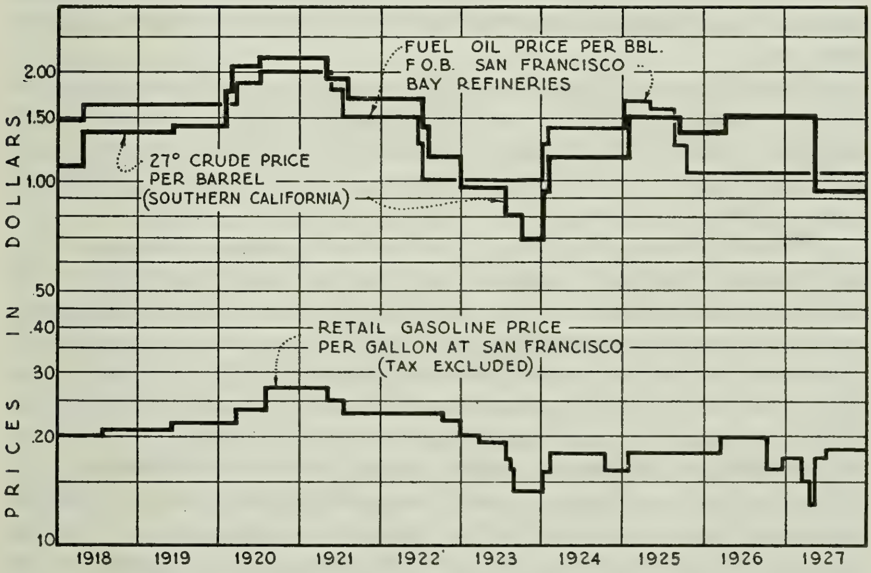


Fig. 4.—California fuel oil, crude and gasoline prices, 1918–1927.

months at the end of 1923, crude prices during much of 1927 were at the lowest levels in the past 10 years, and gasoline prices during April dipped to the lowest point in many years. California prices for the last 10 years are depicted in Fig. 4.

VII. Discussion of New and Prospective Fields

Long Beach Deep Sand.—In October, 1927, interest was renewed in the Long Beach field on account of the completion of four wells with initial

daily productions of 2000 to 4000 bbl. at depths ranging from 5600 to nearly 6000 ft. This opened for development a deeper horizon than many thought existed, and although its effect was of minor importance in 1927, it will likely prove to be one of the most important production factors in 1928. Early in January, 1928, there were 28 wells in this deeper horizon producing a total of about 43,000 bbl. daily. It is thought that these sands will prove productive over much of the area of the old field, as a result of which one may realize the large amount of production which might be developed during 1928 at Long Beach. To date this field has produced approximately 162,000 bbl. per acre of proved oil land.

Rincon (*Seacliff*).—Aside from developments at Long Beach, the discovery of the Rincon field, about 8 miles northwest of Ventura, seems to have the greatest potentialities for the year 1928. The discovery well which was completed the first week in November, 1927, had an initial production of 1000 bbl. daily from a depth of 3220 ft., with a gravity of 29.9° Bé. Since that time, four wells have been completed ranging in production from 600 to 1000 bbl. daily from depths of about 2600 feet.

This field is on a northwesterly extension of the Ventura anticline and the structure indicates that the oil-bearing sands extend well under the Pacific Ocean. Production is obtained from the Fernando formation of Tertiary age and is higher stratigraphically than the productive formations at Ventura Avenue.

Alamitos Heights (*Seal Beach*).—This field is located along the Newport-Beverly Hills fault zone, lies less than half a mile northwest of the Seal Beach field proper, and is a part of that field although it is really a separate high, divided from the main field by a saddle. A major northwest-southeast fault traverses both the Alamitos Heights and Seal Beach fields on the northeast. Surface formations are of San Pedro age (Pleistocene) and these lie unconformably upon the Fernando (Pliocene) in which there are oil sands at depths ranging from 4600 to 5500 ft. The discovery well came in with a production of 1800 bbl. daily of 25.9° Bé. gravity oil from a depth of 4747 ft. The Alamitos Heights area reached a production of 46,382 bbl. in the week ending Sept. 30, and early in January was producing 18,000 bbl. daily. There are 118 completed wells in Alamitos Heights which includes the townlot area, whereas there are only 50 wells in Seal Beach proper, even though the proved area of the older part of the field is much larger. Some possibility of a deeper sand exists in this field similar to the new deep sand at Long Beach. There are at present three wells ranging in depth from 6400 to 6600 ft., two of which have very recently (Jan. 23) been reported as producing about 600 bbl. each, along with heavy cuts.

Ventura Avenue.—This field was extended to the southwest about 1200 ft. in January, 1927, and eastward some 1300 ft. in February. The

extension wells had initial productions between 2000 and 5000 bbl. daily, and were very deep, ranging from 5800 to 6300 ft. An interesting development early in 1928 was the completion of a 2800-bbl. flowing well of 30° Bé. gravity oil at a depth of 7015 ft., in the south central part of the field. This is the deepest well in the world producing oil in large quantities. The only producing well which is deeper is a well in the Rosecrans field, which had an initial production of 45 bbl. daily over two years ago from a total depth of 7591 ft. and is still producing 44 bbl. per day.

Round Mountain.—This field is situated approximately 4 miles east of the northern end of Kern River field near Bakersfield, in an area of rough topography. The discovery well was completed in May, 1927, for an initial production of 350 bbl. of 16.3° gravity oil at a depth of 2073 ft. The structure is generally monoclinal and the accumulation is due to a complex faulted condition with the major fault extending in a northwest-southeast direction. The oil comes from the Temblor formation (middle Miocene) which also outcrops on the surface. There is no pipe line outlet at present and little likelihood that the field will materially affect the 1928 production situation.

Mt. Poso Extension.—In December, 1927, the Mt. Poso field, discovered in 1926, was extended about 2½ miles to the south by a well completed at 1781 ft. for a production of 300 bbl. daily of 15.9° gravity oil. Most of the production in this field is shut in, there being no pipe line outlet. There is an estimated potential output of about 4400 bbl. daily from 11 wells in January, 1928.

The structure of the field is a southwesterly dipping monocline and the productive Vedder zone of Temblor age is truncated and sealed on the northeast by normal faulting. The surface formations are principally of the Kern River Series (probably Pliocene) which lie unconformably upon the Temblor, the latter formation outcropping in places.

Potrero (Cypress).—In September, 1927, after the area had been tested by numerous unsuccessful wildcats, production was obtained at Potrero between the Inglewood and Rosecrans fields in the Los Angeles Basin. The well produced 200 bbl. of 38.6° gravity oil from a depth of 4717 ft. and since the discovery had been deepened to 5408 ft., and is in the process of being cemented, some trouble being experienced in shutting off water.

Buttonwillow.—A large gasser producing 12,000,000 cu. ft. daily was completed in the Buttonwillow area 17 miles northwest of Elk Hills and 12 miles southeast of Lost Hills in August, 1927. Late in 1926 a gasser blew out in this field and caused much damage. A late report states that another large gasser with estimated capacity of 20,000,000 cu. ft. daily has been completed. Still another well is drilling to determine further the amount of gas underlying the area, and possibly to determine the chances of finding oil. The structure of the area is somewhat indefinite,

as it lies under valley alluvium, well out from the large producing fields on the west side of the San Joaquin Valley.

Goleta.—The Goleta field is the most westerly field in the Ventura Basin, being about 10 miles west of Santa Barbara. It lies near the northern edge of that portion of the basin which continues under the Santa Barbara Channel, and is near the south edge of the Santa Ynez Range. The structure is a rather long closed anticline, and production is from the Sespe formation of Oligocene (?) age. The discovery well came in during February, 1927, for 400 bbl of 43.0° gravity oil from a depth of 1331 ft. Eight wells have been completed on the structure, but the total daily average production for December of six of these was only 231 bbl. One well went to 5660 ft. to test deeper formations without successful results.

The Edwards anticline to the west of the Goleta anticline, and in a way an extension of the latter, has also been proved productive by a well completed in October with initial production of 200 bbl. of oil and 200 bbl. of water from 2720 ft. During October, this well produced only 1885 bbl. of oil, and in November produced no oil but 500,000 cu. ft. of gas daily, which declined to 200,000 cu. ft. in December.

Union Avenue, Edison and Fruitvale.—There are indications that a new field may soon be proved, immediately south of Bakersfield in an area overlain by San Joaquin Valley alluvium. One well in July, although never actually completed as a producer, shot a large stream of oil, mud and water over the crown block along with a large amount of gas. The depth was 4392 ft. and much trouble has been encountered, the company now drilling a second well. Another well about 7 miles to the eastward near Edison has also created considerable interest, having produced some oil along with sand and water early in 1928 from a depth of about 4000 ft. A third wildcat a few miles west of Bakersfield, in the Fruitvale district, is also being closely watched by operators.

Production East of the Mississippi River

By R. S. Knappen* and D. V. Carter,* Pittsburgh, Pa.

(New York Meeting, February, 1928)

In the states east of the Mississippi River, oil field operations were generally restricted during 1927. Active drilling was chiefly confined to the flood district of Bradford, and to the new areas in western Kentucky, Michigan, and southwestern Indiana. In spite of the general depression, production increased in every state, except Illinois. This unexpected increase is due to several factors. First, in 1926 there was little flush production outside of Illinois, and the decline curves in all states are exceedingly flat. Second, the floods in Bradford, Pennsylvania, and Allegany County, New York, proceeded normally and increased production in those states for the fourth consecutive year. Third, new pools in Kentucky, Indiana and Michigan gave important flush production. Fourth, the general unsatisfactory market forced the operators to scrutinize carefully all their operations and improve efficiency and production in all possible ways.

Increases amounted to approximately 2,000,000 bbl. Illinois lost 900,000 bbl., leaving a net gain for the states east of the Mississippi River amounting to 1,100,000 bbl., or a total 40,268,000 barrels.

Pennsylvania and New York

In northern Pennsylvania and southern New York, the principal activity centered in the districts where flooding is being used to increase the recovery from the old districts. Once started, the flood cannot be shut off. The producer must drill wells and take his oil on schedule, or irrevocably lose it. Accordingly, in face of an adverse market Bradford and Bolivar operations increased 24 per cent. This area furnished more than 40 per cent. of the oil wells completed east of the Mississippi River last year, although the average initial production was less than 2.5 bbl. Unlike all normal fields, this production increases for several months until water appears in the well. For this reason, these wells will produce much more oil than would appear probable from the statement of initial production.

During the year, air or gas pressure was applied to several new properties. Surplus gas is rarely available and air has been more commonly used. Two explosions occurred as a result of recycling air-gas

* Gulf Production Co.

mixtures. Unless more than 85 per cent. of air is present, the mixture cannot explode. There seems to be good evidence that air-gas mixtures coming from the sand are not homogeneous. Therefore, it is dangerous to compress and recycle such gases carrying over 70 per cent. of air on the average. Data regarding the desirability of combining air or gas pressure with water drive are conflicting. Most operators who have tried repressuring are extending their operations and feel the work is amply justified by the results.

In parts of the field, gas costs over 60 c. per 1000 cu. ft. Power costs are being carefully watched. Electricity is being substituted for gas in some places. A 2 or 3 hp. electric motor with gear reduction unit has been found more economical than an individual engine for pumping small, isolated wells, where a power could not be efficiently operated. Where the well is pumping steadily, however, the higher cost of electricity more than counterbalances the saving in installation and maintenance charges.

The addition of soda ash to the flood waters has not yet increased production. Most of the operators have agreed that it is useless, but one property is still using the chemical. Outside of Bradford and Allegany counties, we do not know that this material is being used in flooding.

In southwestern Pennsylvania, completions declined about 20 per cent. but initial production was off 75 per cent. One small pool was developed by 12 wells in southeastern Washington County. The area was closely drilled and production declined rapidly. A short extension of the Nineveh pool in Greene County was also drilled up early in the year. Outside of these developments, most of the drilling was confined to lease protection.

As already stated, Pennsylvania and New York increased their production for the fourth consecutive year, making 11,879,000 bbl. from 92,100 wells, with a daily average of 0.36 bbl. per well.

West Virginia

In West Virginia there were no important developments—completions decreased 25 per cent. and the total of initial productions was almost 50 per cent. less. However, extremely careful operation enabled the area to increase production about 1 per cent. Output was 6,033,000 bbl., which is the largest for West Virginia since 1923.

Southeastern Ohio

Southeastern Ohio ranked third among the districts east of the Mississippi River in number of oil wells completed and was second only to western Kentucky in amount of initial production. Like most other districts, there was a general decrease in activity compared to 1926.

Many of the wells exceeded 3000 ft. in depth. Their average initial production of 22 bbl. per day makes it impossible for them to pay out, as a whole, at the present price. Many of the oil wells resulted from drilling for gas. Utility companies supplying Pittsburgh, Columbus and Cleveland have been very active in such drilling throughout the central Appalachian area.

Kentucky

Eastern Kentucky decreased its drilling more than a third, and lost one-third in initial productions but drilled more probable territory and so improved the average initial production by one-fourth. There were no important discoveries in this area.

Western Kentucky enjoyed a real boom. Five pools were developed south and west of Pellville, Hancock County. Ohio County secured the bulk of the new production, but Daviess and McLean also participated. The wells are shallow, ranging from 400 to 800 ft. The upper Mississippian sands are irregular and production cannot be predicted satisfactorily. Initial production exceeded 100 bbl. in many cases and development has been correspondingly rapid. Four producing areas were developed during the year. Leasing and drilling were continuing actively at the close of 1927 and promised to increase production considerably in 1928.

In the southern part of western Kentucky, Barren, Allen and Warren counties also had a number of good completions. The wells range from 400 to 700 ft. in depth, as a rule. Drilling is cheap and even though decline is rapid, many of these small areas have proved very profitable.

Tennessee

In Tennessee, at least eight wildcats in Clay, Jackson and Pickett counties developed commercial production. The sands vary from 150 to 700 ft. in depth; initial production exceeded 100 bbl. per day in 11 wells. Poor transportation facilities have considerably hampered the development of the area. Although initial daily productions were reported at 3953 bbl., the year's output was only 62,200 bbl. The high ratio of success in the drilling in this area promises considerable additional development during 1928.

Central and Northeastern Ohio

Central and northeastern Ohio were primarily drilled for gas. Cleveland developed several gassers, the largest making 9,500,000 ft. daily, which is a very large well for this area. Other semi-wildcats found production in the Berea and Clinton sand in a zone extending southward for two-thirds the length of the State. The year's best oil wells were completed in the Clinton sand. Hohnes County had 40 wells averaging 57

bbl. initial production. Other counties were less successful and only six counties in central Ohio completed oil wells during the year. The deep drilling discourages active development on the present market basis.

Lima and Indiana Fields

The Lima and northeast Indiana fields were very quiet. Little drilling was done and the total of initial production was less than half of that in 1926. A wildcat northwest of Tiffin flowed 90 bbl. per day. Otherwise the Trenton completions were not of special interest. Most of them were inside locations. As a rule, they found some oil and considerable water. The extensions of previous producing areas were of slight importance.

Early in the year, several good wells were completed in southwestern Indiana in Sullivan, Gibson and Daviess counties. In northern Sullivan a small pool was developed, yielding 47.7° Bé. oil. Daviess and Gibson counties each reported a 225-bbl. well. Initial productions totaled slightly more than in 1926, and the state showed a 10 per cent. increase in total production, amounting to 853,000 barrels.

Illinois

Illinois had a very unsuccessful year. The development of the Allendale pool in 1926 encouraged the search for new production. None of present importance was found and initial productions slumped over 70 per cent. Total production declined 11 per cent. Two small wells were reported from central western Illinois in Morgan and McDonough counties. The areas do not appear to be of much importance.

Most of the state's drilling was confined, as usual, to the southeastern region. About 55 per cent. of the completions were successful, but initial production was limited. The year's results added little to the present or prospective production from the state.

Michigan

Michigan, like western Kentucky, enjoyed a boom. The Saginaw field was drilled vigorously on a townlot basis. Many wells were completed in the Berea sand for fair initial productions, but because of close spacing they declined rapidly. Average daily production at the end of the year was estimated less than 4 bbl. per day. The Saginaw "sand" at 2300 ft. yielded one big well, the Stetzreide, which flowed 475 bbl. per day. It declined rapidly, however. Offsetting wells secured only small production. The Dundee lies 700 ft. lower. In spite of several shows, it has not yet developed valuable production. By the close of the year, the pool was defined on all sides, and except for possible deeper production it promises little for the future.

Sun Oil Co. completed a 15 or 20 bbl. well near Owosso, 25 miles south of Saginaw. A 3-bbl. well is reported from Van Buren County, in the southwestern part of the state. In December a well was completed near Muskegon on the western side of the Lower Peninsula. This well has been variously reported at 60 to 500 bbl. daily. At least, we know it is producing oil, and shipments are being made by tank car at least once a week. These developments promise a general prospecting campaign for the Lower Peninsula in the near future. The absence of surface information and the heavy cover of glacial drift will make development both slow and expensive.

Summary

Available statistics on the various fields are summarized from the *Oil and Gas Journal* in the following table:

	Bbl.
Pennsylvania	9,642,000
Ohio	7,542,000
Illinois	6,873,000
Kentucky	6,590,000
West Virginia	6,033,000
New York	2,237,000
Indiana	853,000
Michigan	436,000
Tennessee	62,000
Total	40,268,000

Review of the Oil Industry in the Rocky Mountain Region for 1927

By S. Grinsfelder,* Fort Collins, Col.

(New York Meeting, February, 1928)

Although wildcatting was hampered by the general overproduction and low price of crude, several developments, worthy of note in the history of the petroleum industry in the Rocky Mountain region, were made in 1927. This district records production from six new fields, two of these having been heretofore productive of gas. Deeper pay horizons were found in two other oil fields. In order to facilitate transportation from fields, six new oil pipe lines were completed or in the course of construction at the end of the year, and one line is proposed for 1928. Four gas lines were completed, one was under construction, and one was proposed for 1928.

The total production in 1927 in the Rocky Mountain district was 29,591,379 bbl.,[1] a decrease of 7,771,991 bbl., or 21 per cent., from the previous year. This was occasioned by natural decline and the general curtailment of production and drilling. A review of the development by states follows.

Colorado

Production from horizons in the Morrison and Sundance at Craig and at Iles Dome, and the bringing in of the deepest producing well in the Rocky Mountain district on North McCallum anticline (Walden) in Jackson County are the outstanding developments for the year in Colorado.

In March the Midwest Refining Co.'s Parkinson 21 SD, SW SE, Sec. 22 T p. 4 N R 92 W, Iles Dome, Moffat County Colorado, found gas in sands in the Morrison estimated at 15,000,000 cu. ft., and at 3242 ft. an oil sand was encountered in the Sundance. Initial production from this horizon was 2575 bbl. in this well. This structure previously was only productive of water in the sands of the Dakota group but has been producing shale oil from horizons in the Benton. The second well completed by the Midwest Refining Co., No. 18 SD in Sec. 23 was also productive of gas in the Morrison and made an initial of 300 bbl. from sands in the Sundance. By the end of the year three other wells were nearing the completion stage but none of them indicate that they will be as big producers as the discovery. To date the productive area has

* Petroleum Engineer, Union Oil Co. of California.

[1] See tabulation at end of paper.

not been defined on this structure. The oil from these horizons is of asphalt base and is from 28 to 31° A. P. I. gravity.

At Craig, also in Moffat County, Texas Co.'s Knowlton No. 10 was the first well to produce from the Morrison formation in a sand logged from 4226 to 4265 ft. Initial production from this discovery well was 200 barrels.

Early in the year the Continental Oil Co. brought in their Sherman No. 1 on North McCallum anticline near Walden, Jackson County, Colorado. This well producing from the top sand of the Dakota group at 5110 ft. is the deepest producing well in the Rocky Mountain district. The gas associated with this oil is of high carbon dioxide content, and due to cooling produced by rapid expansion at the surface, this well's production is carbon dioxide snow. On warming the carbon dioxide passes off as a gas, leaving a light amber colored oil of 50° A. P. I. gravity. This well has made as high as 400 bbl. of oil a day and is the only producing well to date in this field.

In the old Florence district, there was considerable drilling in the Canon City extension. Twenty-nine completions were made and the production from Florence was increased 98 per cent. over 1926.

In the Wellington-Fort Collins district there was a general curtailment of drilling throughout the year.

Montana

No new discoveries of any great importance were made in Montana. Two small wells were brought in on the Bannatyne structure by the Genow Oil Co. Twelve other wells in the vicinity of these small producers were nonproductive.

Fifty miles northwest of Great Falls on the Pondera structure, the Montana Pacific Oil Co. developed a producer good for 3,000,000 cu. ft. of gas from the base of the Ellis. This well developed a little oil in the top of the Madison lime.

Two new gas fields were found. One, northeast of the middle butte of the Sweet Grass Hills, was developed by three wells capable of producing a total of 34,000,000 cu. ft. daily; the other, Bears Den Anticline in Tp. 37, NR 6 E, was proved by a 15,000,000-cu. ft. gas well.

New Mexico

Runs were made from two new districts, namely Maljamar and Bloomfield during 1927, the latter however, was only for one month and was 600 barrels.

On the Hospah structure in San Juan County, New Mexico, the Midwest Refining Co. brought in the discovery well early in the year. This well made an initial of 200 bbl. per day in a sand of the Mesaverde formation from 1531 to 1536 ft. Deeper Cretaceous sands were only productive of water. One other well on this structure is good for about 50 bbl., while six other completions proved non-commercial.

On the western edge of the Permian Basin of West Texas, Lea and Eddy counties in southeastern New Mexico were the scene of considerable drilling. At the end of the year, however, only three wells attracted attention. In eastern Eddy County, Prairie Oil & Gas brought in a well in 10-17-31, estimated at 75 bbl. In the same county, the Texas Co. brought in a gas well in 25-16-31 which sprayed some oil. The same company completed their Rhoades No. 1 in 22-26-37, Lea County, estimated as a 25,000,000 cu. ft. gas well and about 30 bbl. of oil. Due to its relation to the productive area of West Texas, considerable activity is predicted for southeastern New Mexico during the coming year.

Wyoming

Oregon Basin in Park County was the most active locality in this state in 1927. The Ohio Oil Co.'s discovery well came in, in February, and though its productivity has been variously estimated, it is assured a good well. This well is producing from the Embar formation from 3345 to 3585 ft. Fifteen and five-tenths miles of 8 in. screw-line have been laid to a loading rack 1½ miles east of Cody. Two 80,000-bbl. tanks have also been erected at this site and a 37,500-bbl. tank and pump station have been constructed in the field. As the year closes there are 10 active drilling wells in this field. Oregon Basin, heretofore only productive of gas in the light oil horizons, has the indications of being one of the biggest, if not the biggest black oil field in Wyoming. The oil is 25° A. P. I. gravity and there is considerable gas associated with the oil. A test on Garland Dome in Big Horn and Park counties, completed in the Embar formation by the Ohio Oil Co., was only productive of gas.

At Dutton Creek, a well was completed by the Midwest Refining Co. for 100 bbl. and 4.4 miles of 3-in. oil line were laid connecting this field with the Rock River-Laramie line. The production from this field is from the sands of the Dakota group.

In Niobrara County, the Continental Oil Co. brought in a well on the Ant Hills structure which swabbed 250 bbl. initial.

At La Barge, 12 wells were on production for the last 3 months of the year. The average production per well was 69 bbl. A pipe line is contemplated connecting this field with the Union Pacific railroad 38 miles to the south.

Salt Creek with 103 completions and 28 abandonments produced 3,700,000 bbl. less in 1927 than in 1926.

Cooperative agreements providing unit operation have made gas drives possible in certain areas in Salt Creek and in the Elk Basin field. In these areas the production decline has been arrested.

Utah

In eastern and southeastern Utah, 1927 witnessed the completion of testing of six structures of the salt dome type without developing com-

mercial production. A test of the seventh structure of this type, Paradox Valley, just over the Colorado line, was completed at 6300 ft. and abandoned. Tests of these structures report good showings of oil and gas. Most of these tests have been drilled on top of structure. Two structures, previously tested on top, are being drilled by flank wells. Their completion during the coming year will be looked forward to with interest.

Summary

Development in the industry in this region also embraces two trunk gas pipe lines, one already under construction from Amarillo to Denver and the second proposed from Hiawatha Dome in northwestern Colorado and Baxter Basin in southwestern Wyoming to Salt Lake.

Discoveries in the Rocky Mountains in 1927 will not greatly affect this district's ultimate light oil production. The coming year will witness the drilling of Tertiary structures in western Colorado and eastern Utah. In view of the fact that most of the closed anticlinal light oil structures defined by Cretaceous outcrops have been drilled, the drilling of these so-called Tertiary structures is looked forward to in a hopeful light.

In the event no new light oil fields of major importance are found and with the continued decline of light oil production, the development of black oil reserves will of necessity be called upon to satisfy the demands of this region.

Oil and Gas Lines Constructed in 1927

State	From	To	Name of Company	Size, Inches	Length, Miles
		Oil Lines			
Wyoming.......	Oregon Basin	Cody	Illinois Pipe Line Co.	8	15.5
	Torchlight	Basin	Producers & Refiners Corpn.	2	5
	Dutton Creek	Rock River Laramie Line	Illinois Pipe Line Co.	3	4.4
Colorado.......	North McCallum	Walden	Continental Oil Co.	4	3.5
	Iles Dome	Moffat to Craig Line	Texas Co.	4	6
	Moffat	Craig	Midwest Refining Co.	4	16
New Mexico....	Maljamar	Artesia	Illinois Pipe Line Co.	4	22
		Gas Lines			
Montana.......	Cabin Creek	Miles City	Minnesota Northern Power Co.	8	76.5
	Kevin-Sunburst	Great Falls	Montana Cities Gas Co.	12	70
				10	9.5
Wyoming.......	Hidden Dome	Greybull	Bighorn Gas Co.	8	35.6
	Buffalo Basin	Norwood River Junction	Midwest Refining Co.	14, 12, 10	59.2
	Worland	Buffalo Basin-Norwood line	Midwest Refining Co.	8	7

Comparative Production in Rocky Mountain Region for Years 1926–1927

	Dec. 31, 1926, Number of Producing Wells	1926, Barrels	Dec. 31, 1927, Number of Producing Wells	1927, Barrels
Colorado				
Boulder	5	9,850	5	9,800
Craig	9	1,203,300	11	668,800
Florence	59	149,300	74	295,500
Fort Collins	9	456,500	13	321,400
Iles Dome	3	25,800	5	247,600
Rangely	4	29,100	4	23,800
Tow Creek	3	142,300	8	264,500
Walden			1	47,900
Wellington	13	755,300	18	913,500
Total	105	2,771,440	139	2,792,800
Montana				
Cat Creek	172	998,000	165	785,900
Kevin-Sunburst	650	6,415,000	861	3,566,800
Lake Basin	6	48,800	7	84,800
Total	828	7,461,800	1,033	4,437,500
New Mexico				
Artesia	198	1,020,800	189	555,500
Bloomfield			7	600
Hogback	7	220,000	7	222,500
Maljamar			4	39,300
Rattlesnake	13	315,200	6	333,700
Table Mesa	6	35,000	6	64,000
Total	224	1,591,000	219	1,215,600
Wyoming				
Big Muddy	181	1,199,500	188	1,071,600
Bolton	5	Shut in	5	Shut in
Byron	6	14,000	7	21,400
Dallas-Derby	42	15,000	42	68,900
Dutton Creek			1	7,200
Elk Basin	142	287,000	146	343,600
Ferris	10	24,500	9	21,400
Grass Creek—Light	334	1,015,200	339	964,700
Black	12	Shut in	12	Shut in
Greybull	21	7,200	21	6,300
Hamilton Dome	25	290,000	25	302,200
Hudson	26	64,500	26	113,100
LaBarge	11	75,000	12	63,800
Lance Creek	30	537,500	27	220,800
Lost Soldier	73	1,909,000	72	1,406,000
Mule Creek	41	Shut in	42	183,500
Notches	2	33,500	3	24,100
Oregon Basin			1	779
Osage	89	120,500	89	120,700
Pilot Butte	27	18,600	27	15,300
Poison Spider and South Casper Creek	19	256,300	19	219,200
Rex Lake	4	54,000	4	40,500
Rock River	61	1,120,500	61	971,500
Salt Creek	2,052	17,980,000	2,127	14,273,300
Simpson Ridge	7	56,800	7	21,500
Spring Valley	29	*2,000	28	*1,750
Teapot	62	422,500	63	656,600
Torchlight	15	940	15	500
Wertz	1	*5,000	0	*0
Total	3,327	25,539,040	3,398	21,140,229
Total Rocky Mountain Region	4,484	37,363,290	4,789	29,586,129

* Estimated.

Montana's Oil Industry for 1927

By Ralph Arnold,* Los Angeles, Cal.

(New York Meeting, February, 1928)

Since 1915, when Elk Basin field was brought in, eight oil fields have been developed in Montana and the production has arisen from 50,000 bbl. in 1916 to 8,000,000 bbl. in 1926. The production for 1927 was 5,121,600 bbl. and the total up to the end of 1927 was 27,138,239 barrels.

The eight fields, with their year of discovery are: Elk Basin, Carbon County (1915); Devil's Basin, Petroleum County (1919); Cat Creek, Petroleum County (1920); Soap Creek, Big Horn County (1921); Kevin-Sunburst, Toole County (1922); Lake Basin, Stillwater County (1924); Pondera, Pondera and Teton counties (1927); and Bannatyne, Pondera and Teton counties (1927).

About 170 wildcat wells have been drilled in the state of which 8 were successful and 162 gas wells or dry. Hence, only one out of 21, or 5 per cent. of the wildcats have been successful. The average depth of the wells has been 1600 ft. and the average cost $32,000 apiece.

Up to Jan. 1, 1927, a total of 1376 wells have been drilled in the producing oil and gas fields of the state, of which 904, or 66 per cent., were successful oil wells; 82, or 6 per cent. were gas; and 390, or 28 per cent. were dry. The percentage of dry wells is excessive as compared to the wells in other states, due to the uncertainties of limestone reservoir rocks.

The total production of oil to Jan. 1, 1927, has been 22,016,639 bbl. and of gas 7,265,330,000 cu. ft. The average price at the well for the oil has been $1.47 per bbl. and for gas about 4 c. per 1000 cu. ft. The value at the point of consumption has been about 23 c. per 1000 cu. ft. The total revenue derived from crude oil has been $32,277,119, and from gas $350,613, or a total income to the producer of $32,727,832. Each well drilled in the state has already (to Jan. 1, 1927) averaged a return of over $21,000.

The total number of domestic (Montana) oil and gas companies organized, since the first in 1885, has been 844, of which 702 are still alive and 142 dead. Oil and gas companies registered for operation within the state to Jan. 1, 1927, but with outside charters, are 143, of which 66 are alive and 77 are dead. Outside the few distributing companies, which are included in these figures, the grand total of 997 companies which have

---

* Consulting Geologist.

operated in the state, with few exceptions, have never paid dividends, and most have been total failures.

The total area of Montana is 146,131 sq. mi., and of this 34,397 sq. mi. or 23.5 per cent., is underlain by rocks impossible of oil production; 12,427 sq. mi. or 8.5 per cent., by rocks unfavorable for oil, and 99,307 sq. mi. or 68 per cent., by rocks possibly oil-bearing. These latter comprise the bulk of the eastern two-thirds of the State, or that portion east of the Rocky Mountains. With the exception of Texas and Colorado, Montana contains a greater area of possible oil-bearing rocks than any other state in the Union, but of that area the writer believes that only a very small percentage is potential commercially productive oil land; for in addition to the factors of source and reservoir, is that equally potent element, structure.

Developments in Prospective Fields in 1927

The most important activities of the year center around the Sweetgrass Arch in the northern west-central part of the state. The discovery of oil in the Bannatyne was the outstanding development because of its distance (50 miles) south of the Kevin-Sunburst producing area. Here a true oil sand in the Ellis (Jurassic) was encountered at about 1500 ft., yielding wells producing 30 to 60 bbl. daily of 28° Bé. crude oil, with but little gas. Secondary testing has limited the area of probable production to three or four sections. Oil and a heavy gas pressure of 570 lb. per sq. in. was encountered at 2100 ft. on the Pondera structure, 25 miles northwest of the Bannatyne. The Pondera oil is 28° Bé., but no quantitative production tests have been made in the discovery well, and secondary drilling on the structure has not progressed far enough to indicate the probable extent of the field. These two strikes stimulated wildcatting in the general region but so far only with negative results.

Tests are being conducted at Bynum, 12 miles southwest of Pondera, and at Healy Springs. Unsuccessful tests at Conrad, Butte and on the Marias River, have proved a low syncline on the structural axis of the Sweetgrass Arch in the region of the Marias River. Test wells in the immediate vicinity of the Sweetgrass Hills uncovered considerable gas, possibly 50,000,000 cu. ft. daily, enough to warrant a pipe line to Great Falls. The laying of this line was started in the fall. Several test wells put down for oil were failures, excepting one, the Flat Coulee well, northeast of the hills near the Canadian boundary, which bids fair to be a producer in the Sunburst horizon.

The probable failure of the Kremlin well, west of Havre, which was drilled to over 3300 ft. without result, except for gas, and the failure of the Claggett well in northwest Fergus County to find commercial oil in the Cat Creek sands have been a great disappointment to those who are advocating the possibilities of northeastern Montana. Additional gas wells have been brought in at the center (Cabin Creek) of the Glendive-

Baker anticline in eastern Montana. Encouraging results in the form of gas have been encountered in the test now going down on Hamilton Dome near Big Timber, Sweetgrass County.

The favorable results obtained by deep wells in penetrating the black oil zone (Carboniferous) in Oregon Basin, Wyoming, have stimulated interest in several structures in southern central Montana where this horizon is at drilling depth.

Development in Proved Fields in 1927

In the Kevin-Sunburst field three new pools were opened in 1927. The Flickertail pool in the eastern end of the field has yielded 25 wells so far, producing 25 to 300 bbl. each, the production being quite consistent. The Calpet-Moe-Lorenson pool situated between the old Hogan and Shoshone-Corey pools, has yielded wells with initial productions up to 4000 bbl. This pool is being extended eastward. The Wilcox pool is a southeastern extension of the main field and obtains its oil in the Ellis at the shallow depth of 1350 ft. Wells are drilled in from 8 to 10 days. costing $2500 to $4000, and yielding 500 to 5000 bbl. daily, initial. Kevin-Sunburst production fell off during the year because only 392 wells were drilled, whereas 500 were contemplated. The yield averaged about 12,000 bbl. daily throughout the year. In contrast to the general over-production throughout the United States the refinery requirements of the Kevin-Sunburst region greatly exceeded the average daily production.

Cat Creek showed a gradual decline, although with practically no new drilling it has maintained its production at nearly 3000 bbl. daily. The wells highest on the structure are slumping off until they become dry of both oil and water: properties lower on the structure are said to produce more oil and less water.

There was no new activity in Montana's two black oil fields, Devil's Basin and Soap Creek, there being no market for this grade of oil. Some additional drilling took place in the Big Lake field, near Billings, but with no increase in daily production. Depth to the producing zone (3900 ft.) militates against activity here. The carbon black plant in this field was handicapped by curtailed production due to carelessness in handling water shutoffs.

The immediate market for oil, due to excess refinery demands over production, combined with the favorable outlook both in the Kevin-Sunburst and southern Sweetgrass Arch, will doubtless result in considerable prospecting this year in Montana. It is a notable fact that Kevin-Sunburst field was one of the very few fields in the United States that suffered no cuts in crude during the disastrous year of 1927.

Review of Petroleum Development in Arkansas and North Louisiana in 1927

By L. P. Teas,* Shreveport, La.

(New York Meeting, February, 1928)

Although 1927 in the Arkansas-Louisiana territory will probably pass into history as a year of small profits and little new production, nevertheless during this period two large gas fields were developed; two new oil fields were discovered, and two new oil horizons, hitherto of minor

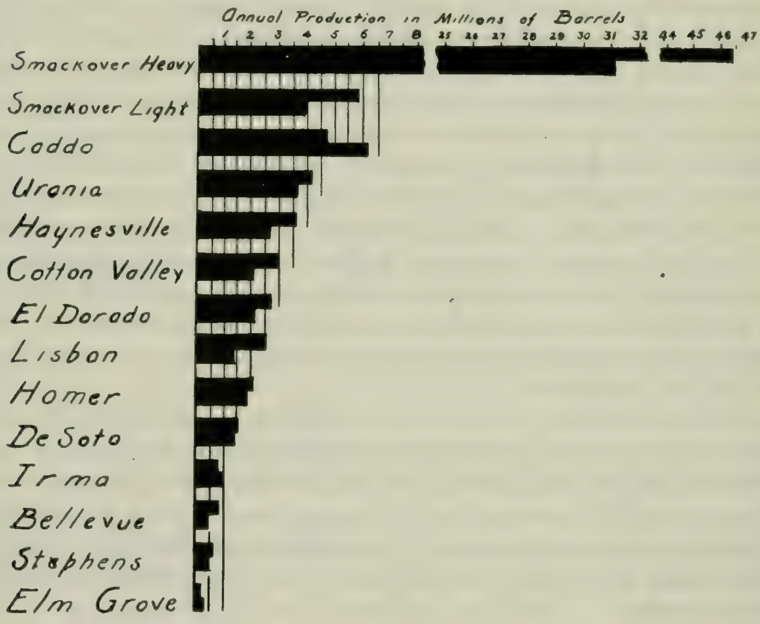


Fig. 1.—Production of North Louisiana and Arkansas by fields, for 1926 and 1927. (Upper blocks represent 1926 production; lower blocks, 1927 production.)

importance, were developed. In spite of the "hard times" some of the leading supply houses did more business this year in this district than in any year since 1920.

* Geologist, Humble Oil & Refining Co.

At the beginning of 1927, Louisiana and Arkansas together produced a daily average of 220,432 bbl. of oil; at the end of the year, 139,990 bbl. (Fig. 1). Production for the year was: Arkansas, 39,819,613 bbl.; North Louisiana, 18,654,386 bbl.; total, 58,473,997 bbl. (Tables 1, 2 and 3.) For the past two years Arkansas and Louisiana have been fourth and sixth, respectively, in the list of oil-producing states.

The total oil produced in this territory since the discovery of oil in Arkansas in 1921, and in Caddo Parish in North Louisiana in 1904, to Jan. 1, 1928, is as follows: North Louisiana, 304,508,826 bbl.; Arkansas, 293,981,201 bbl.; total 598,490,027 bbl.

TABLE 1.—*Production in North Louisiana and Arkansas by Fields*, 1927

District	Total Production, Bbl.	Daily Production, Jan. 1, 1928, Bbl.	Producing Wells, Jan. 1, 1928, Bbl.	Daily Average Production per Well, Jan. 1, 1928, Bbl.
Arkansas				
Smackover heavy	31,149,347	71,150	2,211	32.2
Smackover light	3,762,241	9,200	1,060	8.7
El Dorado	1,671,695	4,073	438	9.3
East El Dorado	454,635	1,132	118	9.6
Lisbon	1,288,188	2,700	344	7.8
Irma	932,000	3,100	77	40.3
Stephens	478,607	1,150	267	4.3
Bradley	55,000	150	2	75.0
Champagnolle	27,900	475	4	119.0
Total	39,819,613	93,130	4,521	20.6
North Louisiana				
Caddo	6,127,815	15,950	1,460	11.0
Urania	3,740,317	7,850	363	21.9
Haynesville	2,673,417	6,750	583	11.6
Cotton Valley	1,993,607	4,800	206	23.3
Homer	1,782,920	4,550	350?	13.0
Bull Bayou	1,402,850	4,200	347	12.1
Bellevue	454,612	1,050	292	3.5
Elm Grove	249,888	600	43	13.9
Pleasant Hill	228,960	840	30	28.0
Total	18,654,386	46,600	3,674	12.7

TABLE 2.—*Drilling Operations in North Louisiana and Arkansas*, 1927

Month	Completions	Dry	Gas
January	86	37	9
February	86	30	16
March	119	56	18
April	100	40	14
May	87	38	16
June	105	47	19
July	67	21	11
August	90	32	17
September	87	36	23
October	82	34	28
November	90	41	20
December	86	28	32
Total	1085	440	223

LOUISIANA

The most significant feature of production in 1927 in North Louisiana was the development of the deeper Pine Island (Caddo Parish) horizons. Although the Dixie Oil Co., Robertshaw No. 53 on Dec. 6, 1925, first gave intimation of the possibilities of oil production in the deeper öolite zones (Dillon zone), and the Gulf, Tyson No. 12, and Magnolia, Robertshaw No. 17 later supported this, it was not until Haynes Brothers brought in their Murray No. 1 in Sec. 14, T. 21 N. R. 15 W., for 6500 bbl. daily of 44° oil at 3685 ft., July 3, 1927, that popular interest was awakened. Since then 24 wells have been drilled, some with discouraging results, until this Pine Island deep pay is now making 5140 bbl. daily. Most of the oil comes from a porous öolitic zone 90 ft. below the upper or gas öolite zone. This lower zone lies about 850 ft. below the base of the 500-ft. anhydrite section in the Glen Rose. The öolites are coarser and the oil more plentiful than in the first zone (Wickett zone) at the base of the anhydrite discovered by the Dixie Oil Co. in 1921. The productive area covers about 400 acres. Along with the development of this lower öolitic zone followed the development of the sand discovered by the Texas Co. in its Caddo Mineral Lands No. 42, Sec. 23, T. 21 N. R. 15 W., Dec. 6, 1926, which flowed 75 bbl. daily. This sand is about 240 ft. below the lower oil öolitic zone and 60 ft. below the top of the sand Glen Rose red beds. It appears that this may be productive over a little more area than is the 3700-ft. sand. By the end of 1927, nine wells were producing 2250 bbl. from this sand with very little water. A total of 2,600,000 bbl. has been produced from these deep zones.

TABLE 3.—*Acre-yield to Jan. 1, 1928, of the Louisiana and Arkansas Fields*

Field	Acres	Acre-yield, Bbl.
Arkansas		
Smackover	21,360	11,200
El Dorado	8,160	4,055
East El Dorado	1,420	5,092
Irma	500	4,400
Stephens	2,100	1,420
Lisbon	2,700	1,275
Louisiana		
Bellevue	900	9,330
Caddo	32,000?	3,550?
Cotton Valley	2,250	4,200
Bull Bayou	11,000?	4,500?
Haynesville	7,060	7,000
Homer	2,500	22,450
Urania	2,500	3,100

Another notable discovery in 1927 was that of the Arkansas Fuel Oil Co. in Logan Oil Co. No. 1, Sec. 33, T. 10, R. 12 W., Sabine Parish, Louisiana, which came in making 480 bbl. daily from 3209 ft. on July 3, 1927. The oil is 41½° Bé. and the producing horizon of Fredericksburg (Lower Cretaceous) age. Although other wells drilled 12 years ago in this vicinity had made a little oil, they were negligibly small, and came from a sand a little above the Logan sand. Some of the wells drilled in the Pleasant Hill field have made upwards of 500 bbl. for some days, but at present the 26 wells now producing are making 840 bbl. daily. The producing area covers about 600 acres, and lies on a southeast trending nose.

On Dec. 12, 1927, the Bensen Oil Co.'s Woolf No. 1, Sec. 3, T. 10 N. R. 13 W., De Soto Parish, Louisiana, about 6 miles northwest of the Pleasant Hill area was completed as a 50-bbl. well at 3003 ft. from the Logan sand. This well is on a small anticline and shows that other fields producing from the Logan sand may be expected in this part of Louisiana.

Several efforts were made in 1927 to realize commercial oil production in the Carterville gas area of north Bossier Parish, notably the Louisiana Oil & Refining Co., Blanton No. 1 in Sec. 23, T. 23, N. R. 12 W.; Doren, et al Bollinger No. 1 in Sec. 9, T. 22 N. R. 11 W., and Walker, Bollinger No. 3 in Sec. 30, T. 22 N. R. 11 W., which on Dec. 8, 1927, was pumping 100 bbl. oil with water and 10,000,000 cu. ft. gas at 3091 feet.

The Tunica Petroleum Co., during 1927, showed in several wells in Sec. 8 and 9, T. 7 N. R. 2 E., La Salle Parish, about 15 miles south of the Urania field, that the top of the Jackson formation deserves serious consideration as a possible commercial producer. These wells are located on a structural nose near a fault, and made as much as 5 or 10 bbl. daily of 20° Bé oil at about 750 feet.

Gas Developments

During 1927 the production of natural gas in Louisiana was increased and stimulated by the completion of more pipe lines. At present refineries, industries and towns in East and Southeast Texas; refineries and towns along the Mississippi River at Baton Rouge and southward, and oil fields, industries and towns throughout a large part of Arkansas are being supplied with Louisiana gas. Projects are being undertaken or seriously considered to pipe Louisiana gas to more remote parts of Louisiana and Texas and also to supply portions of Mississippi, Alabama, Tennessee and Missouri. The recent discoveries of new and large gas areas in North Louisiana have shown that larger and more distant markets can be adequately supplied.

The following data on the withdrawals of gas from the North Louisiana fields in 1927 have been supplied by J. S. Ivy of the Palmer Corpn. of Shreveport, La.

Estimated Natural Gas Withdrawals for Shreveport and Monroe Districts for the Year 1927

Field	Producing Gas Wells	Estimated Withdrawals, Cu. Ft.
Sligo		
Jeter Sand	1	
Woodbine Sands	10	1,054,442,000
	11	
Elm Grove and Caspiana		
Nacatoch Sand	41	
Hutchinson Sand	25	
Woodbine Sands	14	5,569,864,000
	80	
Shongaloo and Springhill		
Blossom Sand	65	14,700,216,000
Cotton Valley		
Davis Horizon	13	5,069,062,000
Pine Island		
Dillon Horizon	19	13,707,529,000
Carterville		
Giles Sand	23	2,645,143,000
Monroe		
Monroe Gas Rock	484	129,845,534,000
Grand Total	695	172,591,790,000

When the Gulf, England Planting Co. No. 1, Sec. 32, T. 17 N. R. 6 E., Richland Parish, 12 miles southeast of Monroe blew on Dec. 1, 1926, for 5,000,000 cu. ft. at 2340 ft., it began an orderly development in 1927 of this new area. On Jan. 21, 1927, the Palmer Corpn., finding only negligible gas in the Gulf's upper sand, went to 2432 ft. and got 19,000,000 cu. ft. of dry gas below red beds that were encountered at 2377 feet.

Both of these gas horizons are in the Trinity and therefore somewhat below the regular Gas Rock of the Monroe field. Since the discovery wells have been drilled in this new gas field, some very large wells have been finished in the southwest part of T. 16 N. R. 6 E., ranging up to 75,000,000 cu. ft. daily. At present at least 25,000 acres seem to be proved in this area. The Richland field is located along the domed unconformity between the Upper and Lower Cretaceous and is associated with an old Lower Cretaceous land mass or ridge. Many have regarded the area as very favorable for oil production, but, although the gasoline content of the gas averages about 200 gal. per 1,000,000 cu. ft., no oil has been encountered in any of the sands down to 3000 ft. By the end of 1927, 23 wells having an initial open flow capacity of 550,000,000 cu. ft. of gas had been drilled. Until recently there was but one outlet for this gas, namely the Natural Gas & Fuel Corpn.'s 14-in. line to El Dorado and Smackover, so that only about 15,000,000 cu. ft. are being taken daily. However, the Interstate Gas Co. is now taking some gas through its line to Baton Rouge.

The Carterville gas area in North Bossier Parish, Louisiana, is another gas field discovered in 1926 and even intimated earlier by showings, but which was not developed until 1927. To Woodley & Collins is due the credit for this discovery in their Roberson No. 1, Section 22, T. 23 N. R. 13 W., on Dec. 7, 1926, when the well came in making 35,000,000 cu. ft. of dry gas, testing 570 gal. of gasoline per 1,000,000 cu. ft. from 3 ft. of sand at 3091 ft. The gas is coming from a horizon about 530 ft. below the base of the Annona Chalk and is probably of Tokio (Austin) age. At present there are 18 wells producing gas in this field and the productive area amounts to about 5000 acres.

During 1927 in North Louisiana, gas was developed in smaller quantities in T. 17 N. R. 16 W., near Greenwood, Caddo Parish, from the Nacatoch sand around 900 ft.

The Sligo Syndicate in Jeter No. 1, Sec. 23 T. 17 N. R. 12 W., found about 2,000,000 cu. ft. of gas, showing 211 gal. of gasoline to the 1,000,000 ft. and later started spraying 5 bbl. of 41° Bé. oil in 10 ft. of sand at 4272 ft. on July 20. This sand occurs 150 ft. below the base of the Glen Rose anhydrite and is somewhat below the upper öolite pay just below the anhydrite at Pine Island. It encourages the hope that the Sligo dome as well as other domes in Louisiana will furnish much oil from the Glen Rose formation.

Temporary interest was created on Feb. 20, 1927, when the Lochanger Oil Co., in Beasley No. 1, Sec. 26, T. 9 N. R. 6 E., Catahoula Parish, had a gas blowout at 3098 ft. from near the base of the Cane River formation just above the Urania producing zone and on Sept. 1, 1927, when the Pittsburg Exploration Co., in its Moore No. 2, in Sec. 12, T. 11 N. R. 6 E., Franklin Parish, also had a gas blowout at 1385 ft. which later caught fire and destroyed the derrick. Although as yet, no commercial gas has been obtained in these areas, such evidence of its existence stimulates the hope that ultimately new oil and gas horizons and areas will be developed in middle Louisiana.

Arkansas

Although a new oil field, Champagnolle, was opened in Arkansas during 1927, the year also brought to a realization the long expected ultimate dependence of the oil fields of Arkansas on Louisiana for their fuel supply, when in November gas from Monroe was turned into the old Crusader Oil Co.'s oil line for use in Smackover, and later in December when the 14-in. line of the Ouachita Natural Gas Co. was completed from the Monroe field to El Dorado and Smackover.

Table 4.—*Production in Arkansas by Fields*, 1927

	Smackover		Lisbon, Bbl.	El Dorado, Bbl.	East El Dorado, Bbl.	Irma, Bbl.	Stephens, Bbl.	Total Bbl.
	Light, Bbl.	Heavy, Bbl.						
January	370,194	3,115,116	155,115	144,216	40,565	69,000	42,992	3,937,248
February	335,499	2,842,415	133,559	132,629	35,612	53,000	38,816	3,571,530
March	357,200	3,056,498	136,996	155,878	40,689	40,000	43,203	3,830,464
April	318,596	2,522,607	121,068	143,823	39,522	70,000	41,017	3,256,663
May	339,671	2,737,574	116,732	151,098	41,063	44,000	43,923	3,474,061
June	326,398	2,637,005	103,331	138,192	34,383	80,000	38,610	3,357,919
July	312,251	2,610,056	100,025	141,453	33,913	69,000	44,312	3,311,010
August	305,106	2,528,019	98,474	142,401	38,792	93,000	35,328	3,241,120
September	287,132	2,395,338	84,958	132,535	32,762	92,000	42,098	3,066,823
October	292,614	2,348,148	85,660	137,237	43,503	104,000	37,830	3,048,992
November	264,220	2,207,279	75,705	127,485	39,315	134,000	34,828	2,882,832
December	253,360	2,149,242	76,565	124,748	34,516	84,000	35,650	2,758,081
Total	3,762,241	31,149,347	1,288,188	1,671,695	454,635	932,000	478,607	39,736,743

Contemplation of this condition brings a feeling of regret when one recalls the giant gassers of a few years ago at El Dorado and Smackover, apparently inexhaustible, that by waste and cupidity of the operators have been reduced to feeble whiffs.

In 1927 the five commercial oil sands of Smackover produced 88 per cent. of the Arkansas oil production and 60 per cent. of the total North Louisiana-Arkansas yield (Fig. 2). The decline of Smackover during the year 1927 has been about one-third. (Table 4.)

The most notable discovery in Arkansas in 1927, the ultimate value of which is still unknown, was the production initiated June 6, 1927, from the Ohio Oil Co.'s Crain No. 1 in Section 1, T. 17 S. R. 14 W. Union County, at 3014 ft., about 150 ft. below the top of the red shale series.

This well, after considerable effort, was brought in for 50 bbl. of 31° Bé. oil from a gray sand in a red bed series, probably of Trinity age, and also at or near the unconformity between the Upper Cretaceous and the Trinity. Later drilling has brought out some interesting wells, notably the Magnolia, Carroll No. 1 in Sec. 1–17–14, which made initially 360 bbl. and was still making 250 bbl. at the end of 1927. Other wells in this area, although larger at first, soon developed considerable quantities of water

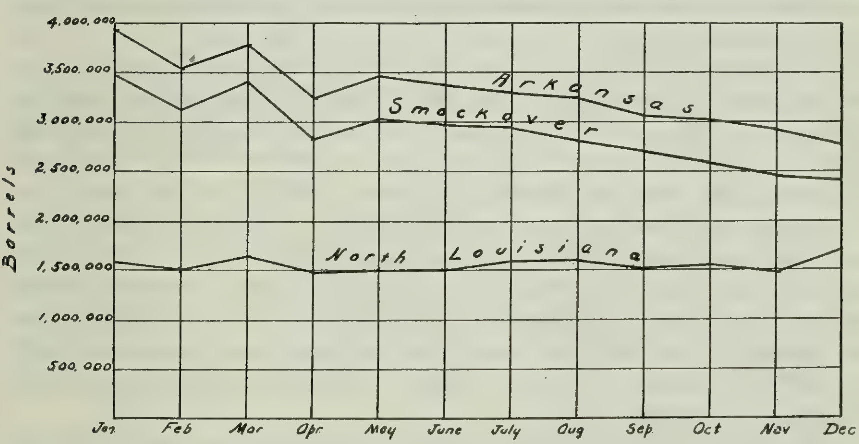


FIG. 2.—SMACKOVER PRODUCTION FOR 1927 COMPARED TO ARKANSAS AND NORTH LOUISIANA PRODUCTION FOR 1927.

or went dead. At present 7 wells make 475 bbl. of oil. Whether the field will stand up under the strain of the close drilling under way is very questionable. At present its area is about 250 acres and the structural relief is small. By the end of 1927, 28,000 bbl. of oil had been produced.

Rovenger in Sec. 4, T. 17 S., R. 14 W. and Garrett & Modisette, later, in Sec. 10–17–14, found small quantities of 20° to 22° Bé. oil in a sand at about 2750 ft. or 245 ft. above the Crain Sand. This new horizon is apparently the true Woodbine and may be correlated with the 2700-ft. gas sand at Smackover. It is hoped that commercial production will materialize here.

The gas developed near Urbana in Sections 8, 9 and 10, T. 18 S. R. 13 W., Union County, Arkansas, in the early part of 1927, by the end of that year had been entirely dissipated and the wells abandoned.

At Smackover a fifth sand was brought to light commercially in the well of Stewart et al, Murphy 6 in Sec. 9, T. 16, R. 15 W., which made initially 200 bbl. of 22° Bé. oil from 2771 ft., March 12, 1927. Since that

time about 20 oil wells have been made in this sand, but they are averaging only about 35 bbl. daily.

During the past year the Lisbon field, six miles northwest of El Dorado, was completely defined; and the Irma field in T. 14 S. R. 21 W., Nevada County, was extended a half mile eastward and its production almost doubled.

Deep Drilling in North Louisiana and Arkansas in 1927

As elsewhere throughout the United States the urge to test out deeper horizons has been apparent in this territory. This condition is very desirable, for the development of deeper sands is one of the most promising prospects for maintaining the position of Louisiana and Arkansas as oil-producing states.

At present the Bellevue, Sligo, Bull Bayou and Pine Island fields are being tested by deep wells. The Humble Oil & Refining Co. joint test in Sec. 15 T. 19 N. R. 11 W., Bliss & Wetherbee No. 30, on the Bellevue dome at 5100 ft., is by far the deepest well structurally in Louisiana. Although this well has already penetrated 2000 ft. of the Trinity red bed series with a rather discouraging section for the production of oil, and has now reentered another marine phase of the Trinity, hope is held out that the base of the Cretaceous, if attained, may yield production. If we count 1300 ft. of Upper Glen Rose removed by erosion subsequent to faulting on the Bellevue dome, this well has already penetrated 4550 ft. of beds assignable to the Trinity formation, by far the greatest thickness of Trinity known.

The Ohio Oil Co. at 6001 ft. in E. K. Smith No. 25, Sec. 12–21–15, Caddo Parish, is within about 250 ft. of being as deep structurally as the Humble well at Bellevue; while the Dixie Oil Co. Jenkins No. 1 in Sec. 9 T. 12 N. R. 11 W. De Soto Parish, at 5907 ft., has encountered no lower Trinity red beds yet and is believed to be 1400 ft. above the present depth of the Ohio, Smith No. 25. The fact that at least the upper part of the red-bed section changes basinward to a shale and lime series as shown in the Dixie, Jenkins No. 1, affords the hope that at some place between these two phases conditions will be favorable for Lower Trinity production on a larger scale than manifested at present.

During 1927 the Palmer Corpn. tested to 5383 ft. the Elm Grove structure, but found no production in the horizons corresponding to the Wickett and Dillon pays at Pine Island in Caddo Parish.

The Glen Rose anhydrite at Cotton Valley maintains steady gas production. Recently the Woodley Petroleum Co., in its Cox B-1, at 4737 ft., just below the anhydrite got a few barrels of light oil indicating that commercial oil production from the Glen Rose at Cotton Valley will be attained.

In Arkansas, Sec. 17 T. 16 S. R. 15 W., the Smackover dome was tested to 4380 ft. by E. M. Jones. Here 1433 ft. of Trinity red beds were

encountered without finding commercial production, although encouraging shows and actual oil were found between 4242 and 4346 ft. Crosbie, in Sec. 33, T. 15 S. R. 15 W., went to 4570 ft. near the top of the Smackover dome and passed through 1740 ft. of red beds. Several shows of oil and gas were reported below 3800 feet.

The Humble Oil & Refining Co. tested without results to 3888 ft. the faulted dome at Falcon in Sec. 9, T. 15 S. R. 22 W. Nevada County.

At Lawson, Garrett & Modisett went to 4309 ft., or about 1400 ft. in the Trinity red beds, encountering oil shows at 3350 and 3800 feet.

Although some of the apparently best structures in Arkansas and Louisiana are being tested without commercial production in the Trinity we must remember that a number of favorable places have not been drilled. The great unconformity between the Upper and Lower Cretaceous also permits of many favorable areas being hidden, where discovery may be possible only by the use of geophysical methods or even by random drilling.

Chapter XIV. Foreign Production

Review of Venezuelan Oil Activities during 1927

By H. J. Wasson, New York, N. Y.

(New York Meeting, February, 1928)

At the close of 1927 Venezuela was producing at the rate of 205,000 bbl. per day, making it the third country in the world in point of present daily production. For the year, the total was close to 64,000,000 bbl., representing an increase of about 70 per cent. over the 37,000,000 bbl. in round numbers produced in 1926. All of the 1927 production came from fields opened up before the beginning of the year.

While no new fields were added to the list of shippers, the past 12 months' wildcatting yielded a fair quota of new discoveries which, in the light of present results, may be considered likely sources of production in due time. Altogether three such promising finds were made.

Of first importance, at least for the immediate future, is the completion by the Lago Petroleum Corpn. of the San Matias well, 4 miles north of the present edge of the Lagunillas field. Although rated as only a 125-bbl. well, at 3217 ft., it indicates a probable extension of the field over the intervening 4 miles between the two.

The two other wildcat discoveries of importance were the Los Manueles well in the District of Colon, which has in all probability opened up a new field about 7 miles north of the present Tarra operations; and the Hombre Pintado well of the Standard Oil Co. of Venezuela, in the State of Falcon, which is considered to be a promising development. Neither of these last mentioned two discoveries will appreciably affect production during 1928, as the Manueles area must await the carrying out of a general plan for the exploitation of the District of Colon, a problem requiring time. The Hombre Pintado area is being tested further, but doubtless several wells will be put down before anything definite will be done towards making the pipe line arrangements that must necessarily precede the commercial exploitation of the field.

The San Matias Well

The San Matias well is a highly significant development. It is located along the trend of the La Rosa-Lagunillas producing formations, and when drilling started, production in the Lagunillas field was 4 miles

away, and in La Rosa to the north 10 miles away. The well thus is about 3 miles from the center of the 14-mile stretch lying between the most northerly Lagunillas field well, and the most southerly well at La Rosa. The finding of oil in this well makes it seem reasonably probable that the Lagunillas field extends for at least 4 miles north, and to a lesser degree probable that the La Rosa productive area extends a further 10 miles south. In fine, it appears that this well has greatly strengthened the probability that these two fields will eventually join together. To many it will seem hardly credible that any single wildcat well could prove such an extensive stretch of territory; however, when it is recalled that both La Rosa and Lagunillas lie along the same major monocline, and that so far as is now indicated there are no closing contour lines separating the two fields, it must appear that the intervening monoclinal territory stands an excellent chance of being productive even before drilling has established this as a probability.

The partial confirmation of this probability, although not unexpected, stands out as one of the momentous accomplishments of the year in the Maracaibo Basin. It forecasts the future development of an oil field some 30 or more miles long, in which substantial areas of 50,000 bbl., and even 100,000 bbl. an acre production may be confidently expected.

It is much too early to hazard a guess as to the quantity of oil this La Rosa-Lagunillas area will produce, but as a tentative estimate, there seems to be a good likelihood that 40,000 acres of productive territory are in sight, and that an average of 25,000 bbl. an acre will be exceeded. These figures combine to make a total of a billion barrels. This quantity, although possibly much too low, or slightly too high, is close enough to indicate the order of magnitude of the situation, and this should compel full recognition of the La Rosa-Lagunillas field whenever the statistical curves of the oil industry are being projected into the future.

East Shore Operations

The activities during the past year along the East shore of Lake Maracaibo, which include the Ambrosio, La Rosa, Punta Benitez, and Lagunillas fields, and the above-mentioned intervening territory, were notable in many respects. The Lagunillas field, at the southern extremity of this sector, though but little over a year old, jumped into first place among the Venezuelan fields with 29,000,000 bbl. for the year, from 71 wells. This field is now nearly 6 miles long, with good production proved at both extremities, and as yet no dry hole having been encountered.

The La Rosa field was substantially extended both to the north and south by the drilling of over 90 wells. It now seems certain that it will merge with the producing areas known as Ambrosio and Punta Benitez, lying respectively to the north and south of La Rosa proper. Hence-

forth, it would seem advisable to refer to these three localities as one, under the general designation "La Rosa."

The developments in the Ambrosio end of the La Rosa field were, during the year, unexpectedly good. Some of the older wells were reworked into good producers, and a number of new wells having initial productions of 2500 bbl. and over, were completed. The drilling continued throughout the year, and 23 wells were completed; however, very little production was drawn from Ambrosio, as all the wells were shut in after brief initial production tests.

In Punta Benitez, the southern extension of the La Rosa field, 28 new completions were recorded, but these operations were not conspicuously successful. Apparently the sand conditions in the vicinity of Punta Benitez are not as promising as in the case in the La Rosa field proper. Such variations in yield are, of course, to be expected in any large productive area, and perhaps the most surprising thing is the absence to date of any sizable spots of definitely barren territory.

Fields, Other than Lake Shore

Elsewhere in the Maracaibo Basin developments were carried on at about the same rate as during the preceding year. These activities are summarized in Table 1. From the table it will be seen that aside from the Lake shore pools there are seven localities listed as producing fields. These are: Mene Grande, El Mene, La Paz, Concepcion, La Tarra, Rio de Oro, and Guanoco.

La Paz and Concepcion were shut down during the greater part of the year, this procedure being possible due to the circumstance that they are one-company fields. The wells in both these fields are of the 50 to 200-bbl. type, but the grade of the oil is higher than that of La Rosa crude, and the wells stand up satisfactorily.

The La Tarra and Rio de Oro fields, in the District of Colon, are located in the extreme southeastern part of the Maracaibo Basin. These areas are comparatively remote from the main lines of communication, and their development has been slow, although the presence of oil was established as far back as 1915. Since that time, nearly 30 wells have been drilled by the Royal Dutch in this Colon area, but no transportation facilities have as yet been provided. The delivery of this oil to the Lake shore will require some 80 miles of pipe line, which must pass through a difficult, swampy jungle country for the most part; so it is evident that a large reserve of "oil in sight" must be proved before commercial exploitation is warranted.

During the year the Colon Development Co. (the Royal Dutch operating subsidiary) completed extensive survey work, considered to be the initial steps toward the working out of a transportation plan which in all probability will be carried out in the not distant future.

TABLE 1.—*Venezuelan Oil Statistics, 1927*

Fields	Drilling Summary								Production				
	Wells Drilled Prior to 1927		Wells Drilled during 1927		Total Wells to Jan. 1, 1928		Average Depth of Hole Drilled during 1927	Wells Drilling at End of 1927	Prior to 1927, Bbl.	During 1927, Bbl.	Cumulative to End of 1927, Bbl.	Age of Field, Years	Gravity of Oil, Deg. Bé.
	Producers	Dry Holes	Producers	Dry Holes	Producers	Dry Holes							
Mene Grande	95	3	42	0	137	3	2,625	9	28,304,882	9,874,531	38,179,413	11	18
La Rosa	226	8	92	2	318	10	2,684	8	34,166,861	19,283,208	53,450,069	5	25
El Mene	104	37	27	17	131	54	1,100	4	5,937,109	2,535,023	8,472,132	4	36
La Paz	21	3	5	0	26	3	1,500	0	1,079,057	227,371	1,306,428	3	25
Concepcion	45	1	19	0	64	1	1,500	0	1,113,839	523,928	1,637,767	3	36
Ambrosio	20	2	22	1	42	3	2,370	3	1,729,317	272,428	2,001,745	2	24
Punta Benitez	3	0	26	2	29	2	2,530	4	133,684	1,146,057	1,279,741	2	26
Lagunillas	7	0	64	0	71	0	3,520	13	1,207,913	28,789,918	29,997,831	2	17.5
La Tarra	10	5	5	3	15	8	1,470	4	75,000	100,000	175,000[6]		30
Rio de Oro	3	0	1	0	4	0	3,105	0	25,000	25,000	50,000[6]		27
Guanoco	6	0	0	0	6	0		0	246,606	614,300	860,906[7]	2	10
Wildcat Operations	5[1]	82[2]	4[3]	18[4]	9[1]	100[2]		16					
Totals	545	141	307	43	852	184		61	74,019,268[5]	63,391,764[5]	137,411,032		

[1] The discovery wells of the several fields are credited to the fields themselves. The 5 wildcats here listed as producers are the shutin wells: Monav 1 and Moneb 1 in Eastern Venezuela; Zambapalo No. 2 in Northern Perija; El Mamon No. 1 in Falcon, and Libertador No. 2 of the North Venezuelan Petroleum Co. in Eastern Falcon.

[2] Contains many holes abandoned because of drilling difficulties; also many that made gas and/or oil, but in non-commercial quantities. Several of these dry holes would, however, have been rated as producers in certain U. S. localities.

[3] The year's successful wildcats are: San Matias No. 1, Hombre Pintado No. 1, and Los Manueles No. 1.

[4] Includes several holes abandoned because of drilling difficulties.

[5] Accurate to within 1 per cent. Error in production figures comes about through difficulty in accounting for oil consumed in drilling, losses from fires etc., and in conversion into barrels of the official reports to the Government, which are made in terms of metric tons.

[6] All the production from the Tarra and Oro fields is consumed in drilling or held in storage, except for a few hundred barrels sold to the Encontrados Light Co. There are no pipe line or other facilities available for handling oil from either of these fields in commercial quantity.

[7] This is a very heavy crude requiring a special tanker for its transport. It is used as a flux in the manufacture of prepared asphalt products.

In the El Mene field, production was held steady at about the same rate as during the preceding year, *viz.*, 2,500,000 bbl. The area of the producing territory was not greatly increased, but a few wells of better than average output were found, and the old wells continued to stand up in excellent manner, so that there were no severe declines to be replaced with new production.

The oil from this field is the highest grade of the Venezuelan crudes. It is a very desirable "sweet oil" and is obtained from the shallow average depth of about 1100 ft. Although lacking in the spectacular glamour surrounding operations in the high-pressure Lake fields, El Mene forms an interesting and important part of the Venezuelan picture.

The Mene Grande field continued its substantial output during the year, recording a production of over 9,000,000 bbl., the largest in its 11 years of life. The field limits were not extended much beyond the outlying semi-wildcats completed in 1926; however, the edge wells that were completed were for the most part satisfactory producers, and the field is apparently no nearer to being delimited than was the case at the end of the last year. The most notable completion was No. 105, on the west side of the field, in territory heretofore thought to be of doubtful prospective value. This well is the deepest producer in the field, 4020 ft., and since its completion in October has averaged around 4000 bbl. a day. This is the first well drilled to the west of the field in 3 years, and opens up rather unexpected possibilities in this direction. It also quite effectively disturbs the tentative production limit line that many observers of the situation had drawn through the present Western edge wells. At this writing it looks as though the great seepage area outlining the north edge of the field marks the only direction toward which important extensions cannot be expected.

The field started the present year, the twelfth year of its productive life, making 50,000 bbl. a day. This is the most it has ever made, but it is thought the actual peak production will not be passed for several years. Being a one-company operation, the production rate is controlled more by market requirements than by the potential capacity of the wells.

During the year 8 strings of tools were kept in operation, and 42 wells were completed. This scale of operations presents an interesting comparison with the rate of activity commonly witnessed in our prolific American fields. In Seminole, for example, 400 drilling operations built up a production of 500,000 bbl. a day, or say 40 operations for each 50,000 bbl., yet, though working in the cream of flush production, the expenditure of drilling effort was five times greater than that expended in the 11-year old field of Mene Grande to attain approximately the same relative tonnage of crude. This is not offered as an invidious comparison directed in criticism against what has taken place in Seminole, but rather as an interesting statistical contrast that would seem to suggest the

compilation of similar yardstick factors for other fields. The number of drilling operations per thousand barrels of output must be a function of the profit, and the suggestion is here made to the statistically inclined that they undertake a bit of research along this line in the belief that a useful series of factors can be evolved which, when properly weighted with production cost and oil price constants, will from a broad viewpoint be helpful in appraising the relative oil merits of countries, states, and general areas, even though widely separated geographically and geologically.

The Guanoco field is the only shipping locality outside of the Maracaibo Basin. This pool is located in Eastern Venezuela, not far from the island of Trinidad. The six small producing wells which compose the field are located near a large asphalt seepage similar in size to the more famous one in Trinidad.

At the close of the year these wells were making about 1000 bbl. a day of 10° gravity oil, which is used in connection with the manufacture of asphalt products.

Prospects for 1928

The question of how much oil Venezuela will produce during the coming year is a matter of considerable importance. Heretofore the successive annual increases, though large from a percentage standpoint, did not involve enough oil quantitatively to exert any appreciable effect on the general market situation. However, under present market conditions the expected increase from Venezuela will constitute a substantial percentage of the surplus oil that will undoubtedly be produced, and run to storage during the year.

For example, the Venezuelan output in 1928 will probably reach a total of 90,000,000 bbl., or an increase of 25,000,000 bbl. over the 1927 output. If, during 1928, crude storage stocks in the United States are increased by 50,000,000 bbl., as seems not unlikely, the expansion in Venezuela during the year will have indirectly contributed 50 per cent. of the unconsumed surplus.

At present writing it seems certain that Venezuela during 1928 will record a production of at least 85,000,000 bbl. (33 per cent. over 1927), although with any sharp dip in the United States production curve having a tendency to stimulate heavy crude prices, there is little doubt that it would pass the 100,000,000-bbl. mark for the year. Considering the various market factors which may tend to restrain any undue expansion, the author's best estimate, admittedly a guess at this time, is 90,000,000 bbl. for the year 1928.

Wildcat Drilling

Drilling in outlying territory away from the proved fields was not on an extensive scale. Although not notably diminished from the preceding year, it failed to increase, due no doubt to the generally poor market

situation and consequent lack of incentive. The three successful wildcat completions have already been mentioned: San Matias, Los Manueles and Hombre Pintado. Of these, the first was drilled by the Lago Petroleum Corpn., and the others by the Colon Development Co. and the Standard Oil Co. (New Jersey), respectively.

Aside from these, there were completed in various parts of the country some 18 dry holes. Four of those were located in Eastern Venezuela, the others being in the State of Falcon, and the Maracaibo Basin proper. A few of the holes listed as dry were abandoned primarily because of drilling difficulties. Some encountered showings of oil in almost commercial quantities, and in fact could doubtless have been made into producers under more favorable marketing conditions. On the whole, the wildcat results for the year show 3 out of 21 successful completions, which may be considered a satisfactory average.

Summing up the results of the year, the thing that most prominently stands out is the large increase in proved and semi-proved reserves that has taken place along the East side Lake fields La Rosa and Lagunillas. The comparatively small amount of drilling necessary to sharply increase production and reserves at the same time, is also noteworthy, and should be borne in mind when considering the economic aspects of the Venezuelan operations. The wildcatting activities, though recording numerous failures, were successful in the case of nearly 15 per cent. of the operations, which in most new regions would be considered exceptionally satisfactory. Finally, the picture of the year is not complete without a word concerning the general spirit of cooperation between the operating companies themselves and between the companies and the Government, that has attended and continues to surround the Venezuelan operations with what might be termed a splendid economic environment.

Much of the production comes from the La Rosa-Lagunillas area, where the ownership is divided among three large companies and competitive conditions prevail. The common boundaries cutting through prolific territory are literally miles in extent, but in all this area there are not over 30 rigs in operation, and these are about equally divided between the three companies. The absence of a more diversified ownership, of course, makes it a comparatively simple matter to arrive at agreements covering the restriction of drilling. Moreover, the absence of any Venezuelan equivalent of our Sherman anti-trust law greatly facilitates the same desirable end. Whatever may be the special conditions, however, that make possible a conservative, may one not even say, sensible rate of operations in Venezuela, the industry and the country should be given credit for being at present one of the outstanding good examples of what should be done in the way of exploiting an exceedingly prolific natural resource for the mutual welfare of the nation and its citizens, and the capital groups in whose hands the operations have been entrusted.

Russian Oil Fields, 1926 to 1927

By Basil B. Zavoico,* Enid, Okla.

(New York Meeting, February, 1928)

There were no radical changes in the petroleum situation in the Russian Soviet Union during the 1926 to 1927 operating year. The developments of the previous year were continued, but the major undertakings were far from being completed. The pipe lines from Baku to Batum and from Grozny to Touapse, and the large refineries on the Black Sea are delayed in their completion by the insufficient authorizations; until their completion the changes in the general situation will be necessarily of a halfway nature.

The marketing situation was subject to much controversy during the past year and, though certain statements are quite true, the bulk of the criticism against the petroleum industry hardly deserves mention. The home market in Russia is steadily growing, with the per capita kerosene consumption already exceeding the prewar figure and fuel oil consumption obviously gaining. The foreign trade is making rapid and well-grounded success, but continues to suffer from low world quotations. There is no apparent sacrifice of home consumers in favor of export trade.

The production of all Russian fields increased by 13,750,000 bbl. as compared with the 1925 to 1926 operating year, and next year's program anticipates a further increase of 9,720,000 bbl. (Table 1). The increased and improved refining facilities will make the real gain in production in the next year even larger than these figures indicate.

Table 1.—*Production in All Russian Fields (Millions of Barrels)*

	1916	1922–23	1923–24	1924–25	1925–26	1926–27	1927–28 (Est.)
Baku	55.81	25.30	31.30	33.90	39.98	49.00	56.80
Grozny	12.33	10.90	11.80	15.14	18.00	22.20	23.70
Emba	1.82	0.97	0.90	1.43	1.57	1.83	2.00
Kouban	0.40		0.25	0.40	0.34	0.59	0.65
Central Asia	0.44		0.15	0.25	0.21	0.21	0.25
Saghalien					0.13	0.15	0.30
	72.80	37.17	44.40	51.12	60.23	73.98	83.70

* Mining Engineer and Geologist, Sinclair Oil & Gas Co.

Production in the Baku District

The crude oil production of the Baku district increased 23.5 per cent. during the past operating year, reaching a total of 49,000,000 bbl. (136,-700 bbl. per day), as compared with 39,980,000 bbl. for the 1925–1926 operating year. The program for the 1927–1928 operating year contemplates a production of 56,800,000 bbl. (159,500 bbl. per day), or an increase of about 16 per cent. over the year just ended.

The relative importance of the six major fields of the district for the past two years is shown on Table 2.

Table 2.—*Relative Importance of Six Major Fields of the Apsheron Peninsula (in Percentage of Total Production)*

Fields	1925–26	1926–27	1927–28 (Est.)
Surakany	19.7	29.4	31.47
Bibi Eibat	25.9	23.0	23.88
Ramany	16.7	15.1	14.00
Sabunchi	16.8	14.7	13.02
Balakany	13.5	12.2	11.23
Binagadi	7.4	5.6	6.40

The figures for the past and for the future operating years indicate that the Surakany field is responsible for approximately one-third of the whole Baku area output, while in the past that field produced but one-fifth of the whole This increase is due primarily to the development of the V-th horizon of the Balakany Section of the Oil Measures, that horizon alone accounting for about 70 per cent. of the new production for the 1927–1928 operating year. Next in importance is the Bibi Eibat field, which, though retaining the same position in the total production, is steadily forging ahead. The Bibi Eibat output is maintained by deep drilling in the old area (to the Kirmakou Section of the Oil Measures), and also by new well on the Bay Extension exploiting the shallower horizons. The production of both above-mentioned fields may be considered as flush, but the area of these fields and the prospective potentiality of the deeper horizons is such that the production from them may be conservatively counted on to increase for three or four years at least. In this connection it is well to point out that in addition to the Pliocene production the Baku area may produce from the Miocene and from the Oligocene formations, which as yet remain untested, and which show oil saturation where outcropping (Chail Dag Mountain). The depth of Miocene and Oligocene beds in the present fields should not exceed 4500 to 5000 ft., and with modern rotary equipment, no difficulty should be experienced in reaching lower horizons.

Drilling

The total footage drilled during the 1926–1927 operating year increased 26 per cent. as compared with the last year, reaching a total of 837,500 ft. The next year's program calls for 976,000 ft., which figure just about doubles the maximum pre-nationalization record. The wildcat and semi-wildcat drilling operations took 112,500 ft. out of the 1926–1927 year footage, and next year's plan calls for 128,000 ft. for the same purpose.

Figs. 1 and 2 show the progress of the drilling operations in the Baku district. It should be especially noted that while in 1913 the old rod-

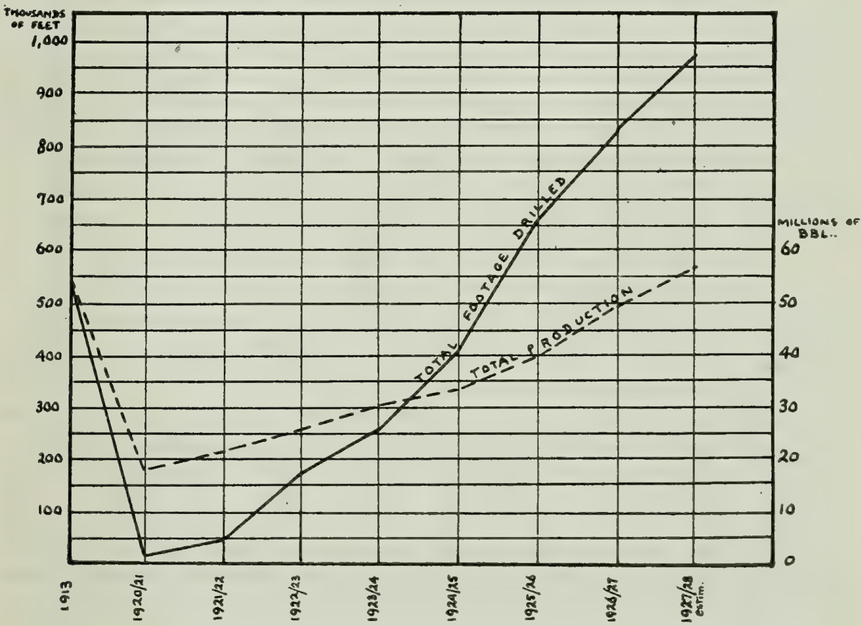


FIG. 1.—DRILLING AND PRODUCTION RECORDS FOR THE BAKU FIELDS. Production curve is superimposed in order to stress necessity of active drilling campaign in order to increase production.

percussion method was actually responsible for 100 per cent. of all drilling, in the 1926–1927 operating year only 7.1 per cent. of the total footage was made by old rigs, and that it is to be entirely abandoned during the coming year. The Russian turbo-rotary drilling method was further developed, and on rotaries automatic feeding apparatus of American and Russian designs was being widely introduced. (The turbo-rotary drilling method consists of a pipe lowered into the well, with a high-pressure pump connection on top to force the mud fluid into the hole. The pipe is stationary, while on its lower end there is a small

turbine operated by the down-flowing mud which rotates this cutting bit. Further details of this method are not available at this time.)

The 1927–1928 program anticipates the completion of 463 producers, 47 semi-wildcats, 31 wildcats, 116 re-conditioned wells and 73 plugging operations, while the total number of operations during the year is to reach 1128.

The modernization of the drilling equipment was responsible for the very marked increase in the rate of drilling and also in the decrease of the

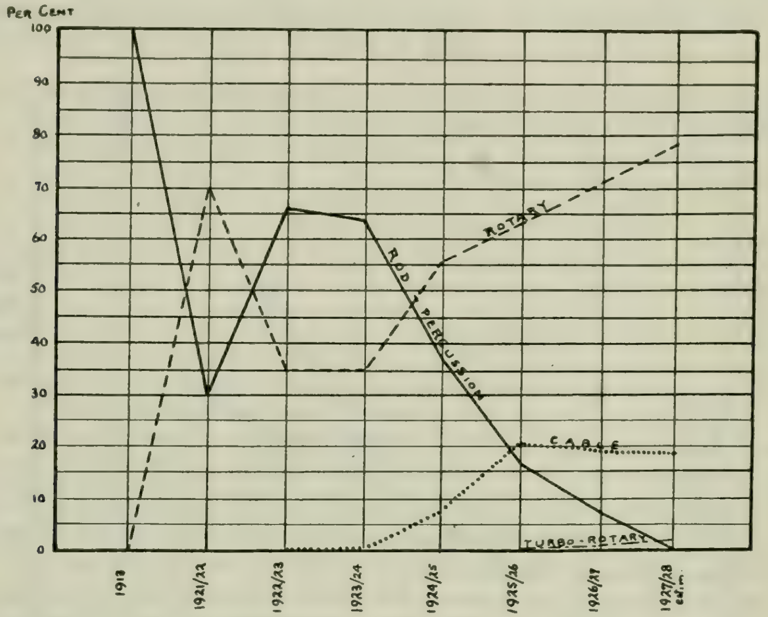


FIG. 2.—ANALYSIS OF DRILLING OPERATIONS IN BAKU DISTRICT.
The 1921–22 year relationship of rotary and rod-percussion methods is only apparent since footage for that year was practically negligible.

cost per foot. Whereas in 1920 an active rig drilled only 30 ft. per month, the 1925–1926 averages show 230 ft. per active rig, and at the present time individual rigs show as much as 2100 ft. per month. Accordingly, a 2300-ft. well, which in former years required 12 mo. of drilling, is now being completed in 60 to 70 days. The cost of drilling dropped as radically from $62.80 per ft. in 1923, to $27.30 per ft. in the first half of the 1926–1927 operating year.

Table 3 shows the depths of the producing wells to be completed during the 1927–1928 operating year, and it becomes at once evident that compared with the 6000-ft. producers of Oklahoma and California, the Baku oil fields may be considered as very shallow. This table indicates also that the deeper horizons remain untested.

TABLE 3.—*Average Depth of* 1927–1928 *Producing Completions in Baku Fields*

FIELDS	FEET
Balakany	1480
Sabunchi	1825
Ramani	1950
Surakany	2750
Bibi Eibat	2050
Binagadi	1600
Average	2020

Refining

The refining branch of the Azneft is still in the transient stage. The construction of pipe lines to Batum held up the building of large units in Baku, while the Batum refineries will not be ready for operations until the end of 1928 at the very best. Evidently the final plan is to refine all exportable products in Batum, using pipe lines to transport the crude from Baku, thus avoiding the expensive railroad traffic. The Baku refineries will take care of the home market, probably with the exception of the gasoline, which will be exported from the Baku refineries to Batum by rail, because of the insufficient home demand of that product.

Meanwhile the increased runs are achieved entirely by means of topping the crude, obtaining kerosene and gasoline, and disposing of the residue as the fuel. Such procedure offers a temporary relief, but will eventually prove most expensive, because of the waste of useful fractions lost in the fuel oil. However, the Central Government in Moskow is proceeding along the lines of least resistance, and because topping operations are furnishing immediate revenue at the minimum of capital expenditure, the topping plants are most favored at the moment. Even in Batum the new refineries will be chiefly of the topping type, only the latter gradually changing to those of the complete cycle.

The quantitative increase in Baku crude runs is due to the substitution of the old boiler stills by the modern ones of the tubular type. These new stills are responsible also for the larger recovery of gasoline and kerosene, because of the greater heating surface and also because they are leak-proof. Many of the older units were losing a large percentage of lighter fractions by leakage alone.

The new construction in Baku, in addition to tubular stills distributed over several older refineries, includes a new refinery, just completed, specializing in lubricating stocks and running topped crude. Its capacity is estimated at 2,150,000 bbl. per year, thus adding considerably to the exportable products. The construction of cracking stills in Baku is so far on an experimental scale only and is of no immediate commercial importance. The capacity of the refineries which are being built and planned for Batum is 11,500,000 bbl. per year, or 32,300 bbl. per day.

This estimate should be reached by October, 1929, while one refinery should be ready by October, 1928. In addition to building refineries in Batum, the Azneft completed there during the past year one kerosene treating plant (1,160,000 bbl. per year capacity) to meet the standards of European markets, and the Standard Oil Co. of New York also built a similar plant. (The Standard Oil Co. of New York plant was completed in August, 1927, at a cost of $250,000.)

Grozny District

The Grozny district of the Northern Caucasus gained in production, refining and export of petroleum, very considerably in excess of the originally proposed program. Total production was 22,200,000 bbl. (62,300 bbl. per day), an increase of 25 per cent. over the previous operating year. The 1927–1928 plan anticipates the production of 23,700,000 bbl., which may be somewhat exceeded if the railroads can undertake to move more. Table 4 shows the gradual falling off of gusher production in the Old Grozny field, and the gains in the New Grozny field, where production is derived almost entirely from flowing wells.

Table 4.—*Production from Flowing Wells in Grozny District*

Field	1924–25, Bbl.	1925–26, Bbl.	1926–27, Bbl.	1927–28, Bbl. (est.)
Old	3,700,000	4,110,000	2,880,000	1,860,000
New	5,150,000	7,020,000	11,200,000	13,600,000
Total	8,850,000	11,130,000	14,080,000	15,460,000

In the New Grozny field the XVI-th producing sand was found to be most prolific, and flowing wells in excess of 11,000 bbl. initial are not uncommon. This horizon is to be developed actively, as soon as the transportation facilities are adequate.

Table 5.—*Analysis of Production in Grozny District*

	Oct. 1, 1926		Oct. 1, 1927		Oct. 1, 1928	
	Number of Wells	Percentage of Total Production	Number of Wells	Percentage of Total Production	Number of Wells	Percentage of Total Production
Type of well						
Mechanical	389	40.2	448	36.0	497	34.6
Flowing	11	59.8	23	64.0	30	65.4
Method						
Pumping	285	61.7	382	81.2	445	
Bailing	89	27.2	55	12.7	39	
Swabbing	14	11.0	10	6.0	12	
Air-lift	1	0.1	1	0.1	1	

The analysis of production, Table 5, indicates that the flowing wells continue to contribute approximately two-thirds of the total from but few wells, therefore allowing this area to be classed as flush. It should be noted, however, that the flowing wells of Grozny show remarkably good decline curves, partly due to careful spacing, and partly to very favorable structural and sand conditions.

The electrification of producing wells resulted in very considerable fuel economies. The actual progress is shown in Table 6.

TABLE 6.—*Percentage of Mechanical Production of Crude in Grozny, by Power Used*

Power	1925–26	1926–27	1927–28 (Est.)
Steam	45.5	9.1	5.9
Internal combustion engines	11.5	13.7	10.7
Electric motors	43.0	77.2	83.4

The total footage drilled continued to show a slight increase, but because of the availability of flowing wells and lack of additional transportation facilities, the drilling is still restricted, and the increased footage is made mostly in wildcat areas. By method, the rotary system gained ground at the expense of the cable tools, while the electric motors were being actively introduced as drilling power. The depth of producing completions in Grozny averaged 1520 ft. during the past year. Table 7 shows the drilling activities of the Grozneft.

TABLE 7.—*Drilling Operations in the Grozny District*

	1925–26, Ft.	1926–27, Ft.	1927–28, Ft. (Est.)
Drilling method			
Cable	214,000	174,000	160,000
Rotary	59,000	121,000	136,500
Deepening	16,500	9,900	13,300
Total	289,500	304,900	309,800
Power used, percentage of total footage:			
Electric motors	6.6	17.2	
Internal combustion engines	12.2	9.9	
Steam	81.2	72.9	

The reconnaissance drilling during the past year was pursued in 17 districts by 22 wells, with a total footage of 29,200. In the 1927–1928 operating year it is planned to do wildcatting work in 20 new areas by 35 wells, drilling 36,000 feet.

The Voznesensky field opened in 1924 is being actively developed. The production for September, 1927, reached 10,200 bbl. from 11 wells,

as compared with 5900 bbl. from 6 wells in October, 1926. Thirteen new wells are now being drilled in this field. It is planned to increase the production of Voznesensky to 2,000,000 bbl. per year by 1932.

On Kerch Peninsula of Crimea the Grozneft is drilling three deep tests, and investigating much of the probable area geologically. The value of this prospective territory is in its proximity to the Black Sea, which makes its production easily available for the export trade.

Refineries of Grozny increased their runs, the 1926–1927 operating year total crude runs reaching 20,700,000 bbl. Table 8 shows the total runs for the last 3 years and the estimate for the 1927–1928 operating year.

TABLE 8.—*Refining Operations in Grozny District*

	1924–25, Bbl.	1925–26, Bbl.	1926–27, Bbl.	1927–28, Bbl. (Est.)
Total crude runs	13,400,000	16,350,000	20,700,000	22,000,000
Production Obtained in Percentage of Crude Runs				
Gasoline	14.23	15.05	15.35	16.10
Kerosene	9.81	10.76	14.40	14.80
Fuel oil, etc	72.45	70.47	66.75	65.60
Losses	3.51	3.72	3.50	3.50

In addition to the gasoline obtained from the straight crude runs, about 150,000 bbl. was produced by three natural gasoline plants. The gasoline content per 1000 cu. ft. of gas averages 7 gal. for the whole district, the maximum being about 14 gallons.

The 10-in. pipe line from Grozny to Touapse on the Black Sea is under construction, about 150 miles of pipe being already in place and welded, the total length of the line being about 400 miles. Total expenditures on the line and refineries in Touapse reached $4,200,000 to date. The capacity of the refineries in Touapse is planned at 30,000 bbl. per day. The line and plants were to have been ready for operation Oct. 1, 1928, but probably will not be completed until more than a year later.

The short pipe line from Grozny to Petrovsk on the Caspian Sea moved 3,700,000 bbl. in 1926–1927, as compared with 2,750,000 bbl. during the 1925–1926 operating year.

The geological department of the Grozneft recently figured the known reserves of the Grozny district, estimating oil in sight at 520,000,-000 bbl., of which amount 400,000,000 bbl. lay in the New Grozny field.

URAL-EMBA

The production of the Emba district reached 1,825,000 bbl. during the 1926–1927 operating year (5120 bbl. per day). This figure compares

with 1,570,000 bbl. in the previous year and with 2,000,000 bbl. planned for the 1927–28 operating year. The Dossor field produced 85.7 per cent. of the total output (from 100 wells); the Makat field furnishing the remaining portion. The next operating year anticipates doubling the Makat field output, due to recent discoveries there. Some of the new wells in Makat make about 250 bbl. per day, this being considerably in excess of the normal settled production. In the Dossor field a recent completion (No. 202) had a natual flowing production of 1000 bbl. per day from 720 feet.

Saghalien

So far all the active work done on Saghalien Island has been by the Japanese, but because of the checkerboard nature of the concession, the Russian Oil Trust is being forced to develop its properties at the earliest moment. The organization of the Saghalien Oil Trust is already completed, and the work will start at the opening of the 1928 navigation season.

The present status of the Japanese development is as follows: in Okha field (a 15° anticlinal fold) 11 wells were drilled, the deepest one being 2940 ft. Five oil horizons were uncovered. The oil is of heavy type, being 21.5° Bé. In Nutovo field (80° east dip and 60° west dip sharp fold) three wells were drilled, total footage being 3300 ft. Seven oil sands were encountered, the oil being of 40° Bé. and yielding 30 per cent. of gasoline and 30 per cent. of kerosene. In Katangli field five tests were drilled aggregating 4500 ft. and showing heavy oil of Okha type.

Production so far is obtained only in the Okha field where 150-bbl. wells are encountered at 350 to 770 ft. During the first year of development, 1923, 6923 bbl. was produced in Saghalien; in 1924 production reached 84,000 bbl., in 1925 100,000 bbl.; in 1926 about 130,000 bbl., no figures being available yet for 1927. The Russian Oil Trust plans to drill eight wells in the Okha field during 1928 and estimates the production for that year at 120,000 barrels.

Saghalien Island's greatest handicap is its climate, the sea being open only for 4½ months each year, thus necessitating large storage capacity on the island and a very active but short tanker traffic. The market is readily available almost without competition.

Kuban

The Kuban-Black Sea district was put under the Grozneft Oil Trust management and that trust is planning an active wildcatting campaign, in order to develop large production near export points. The production of the Kuban fields reached 590,000 bbl. during the 1926–1927 operating year as compared with 519,000 bbl. in the past year. No new definite

discoveries were made in the area. In the Kalujski field well No. 3/26 made 900 bbl. of 29° Bé. oil in 16 hr. from 610 ft., but that production did not last long. Deeper drilling in the area from Grozny to Crimea will undoubtedly uncover large fields, but the discoveries will require much preliminary geological work and location of wells on gentler folds.

Turkestan

Production of the Turkestan (Fergana district) remained stationary for the past two operating years at 213,000 bbl. The next few years should show considerable increases because of the discovery of the new field in Shor-Sou, near the railroad station Posetovka. The first well drilled there came in for 400 bbl. initial, settling to 180 bbl., while the second well settled to 250 bbl. per day. Production is encountered at 650 ft., and the productive area is estimated at 1600 acres. All production of the Fergana has a readily available market, because no coal resources are available in the Turkestan, and because the district will be considerably industrialized by the cotton, wool and fruit-canning industries.

In Trans-Caucasus (Georgia) in the Shirak district, the Italo-Belgian group obtained a concession in 1924. The reconnaissance part of the concession covered 5 years, and the exploitation part 30 years. However the concessioners are apparently very slow in the development work and will let the concession lapse without any serious work being done.

In other parts of Russia the Central Oil Trust is planning to do reconnaissance work along the Volga river, north of the Sea of Azoft and in the Crimea. However, funds made available for such work are entirely insufficient for undertaking careful reconnaissance.

Financial Position

The Russian oil industry is operating at the present time under a system which may be classed as State Capitalism. Every major district is a fairly independent managing and operating unit called a trust (Azneft, Grosneft and Embaneft). All these so-called trusts depend on the Central Russian Oil Trust with headquarters in Moskow. The Central Trust and its subdivisions are operating very much like a large American company and its subsidiaries. However in all their major decisions, plans for the future, price structure of their products and the marketing, all trusts are under direct orders of the Central Government Planning Committee. This Committee is presumably balancing all the industries of the nation and dictating the prices as it sees fit and not according to the law of supply and demand. Also it finances poorly managed and deficit-making industries by withdrawing capital from stronger units. The net result of such a plan is to unbalance the stronger units, while not getting at the

root of the trouble in weaker industry trusts. Provided the political conditions remain the same State capitalism of the above order will result in a slow and gradual growth of all industries, whereas otherwise the stronger units would effect large organizations, pulling along and financing the weaker units. All these assumptions are made considering that all men will do their best, but under the present form of remuneration (necessarily adopted under communism) the men, while doing what is demanded from them, are not exercising their ingenuity, their talents and their stick-to-itiveness, especially since their best efforts are turned back by the red tape and bureaucracy of the Central Committees.

Table 9 shows the gross income of different trusts after amortization, but before royalties and taxes due to the Central Government.

TABLE 9.—*Gross Income of Russian Oil Trusts (Millions of Dollars)*

	Azneft	Grozneft	Embaneft	Total
1922–23	2.05	2.10	0	4.15
1923–24	7.45	8.40	0	15.85
1924–25	12.15	14.60	1.15	27.90
1925–26	16.65	17.45	1.45	35.55
1926–27	26.80	23.10	1.45	51.35

It would appear therefore that the oil industry is in position to accumulate certain reserve capital and to expend considerable amounts on major and absolutely necessary improvements. However, as indicated once, the Central Government requires finances for other industries, especially so in foreign currencies, and the oil industry is made to pay.

MARKETING

The marketing situation of the Russian oil industry is extremely complicated. The relationship of the foreign exports to the interior trade especially was a matter of much discussion during the past few months; most unfortunately however this problem was criticized and subsequently defended not impartially but under the influence of the competition. The most careful analysis of the situation does not warrant the statement that the home market is sacrificed by increasing the exports. The factor which must not be forgotten is that Russia was devastated by successive revolutions much more thoroughly than by any enemy invasion, and not in part, like France by Germany, but in the whole, the destruction being most complete in the industrial districts. Therefore the reconstruction of Russia will take much more time than does the same process in western Europe and only now the country is beginning to break the prewar industrial records. The most serious problem, not faced by western European nations, is the rebuilding and

disciplining of the human factor loosened by the class war. It is accordingly entirely illogical to expect the growth of petroleum consumption in Russia on a basis at all comparable with other powers.

Prospects for the Industry

The Russian oil industry at the close of the 1927–1928 operating year will reach a stage where it will be in position to increase the crude output considerably. Large increases may be anticipated in the new Grozny field and also from Baku, although no new fields of major importance have been opened there as yet. Saliani and the Puta trend may eventually rank as first-class fields, but their development is yet several years ahead. The production of the three major fields of the Apsheron Peninsula is remarkable, having been in excess of 150,000 bbl. per day for more than 30 years. Even now it may be conservatively assumed that production from the three fields will reach 200,000 bbl. per day and stay at that rate for another 10 years at least. No extensive wildcatting has been done yet anywhere. The surface indications as well as the structural features of the Caucasian uplift undoubtedly favor the presence of large oil accumulations around the core of the mountains. The Volga river region, Crimea, Turkestan and Saghalien are among other prolific areas either untouched or but scratched. It should be also remembered that the deepest hole in Russia probably has not gone much farther than 3000 feet.

The outlook for the industry accordingly may be stated as follows: Very rich petroleum potential reserves, oil in sight sufficient for at least 5 years of rapidly growing production; refining and transportation facilities increasing by about 25,000,000 bbl. in the next 2 years, and the markets sufficient to take care readily of any increase that the Russian Oil Trust may reasonably be expected to effect in the next few years.

DISCUSSION

B. B. Zavoico.—The chief petroleum resources of Russia are associated with the Central European uplift which can be traced from the Alps through the Carpathian mountains, to the Crimean peninsula, the Caucasian Mountains and to the Himalayas.

The fields may be roughly divided into two classes. The first class is familiar to all; the oil accumulations are due exclusively to favorable structural conditions, usually anticlines, faulted structures or river bed accumulations. The Grozny fields are one example and the Kuban fields another. In Grozny there are seven definite producing sands with edge water encountered as the sands are exhausted, the structure being a very sharply folded anticline, probably faulted. The Kuban fields are of the river sand deposit type and are of relatively minor importance. In the future a very large area of the Northern and Central Caucasus will undoubtedly be spotted with some of the largest oil fields the world has known. All of the fields of that area will be of purely anticlinal type.

The second class of oil fields is entirely unknown elsewhere in the world. In Baku, on the Apsheron Peninsula, the producing oil measures of the Pliocene average 4500

ft. in thickness, and consist of about 75 per cent. of sand and 25 per cent. shales and clays, the two formations interlensing through the whole thickness of the oil measures with but one or two beds carrying through. In the above-mentioned thickness of 4500 ft., there are as much as 30 to 50 different pay horizons. Production per acre in the Bibi-Eibat field over a large area reached an average of 2,500,000 bbl. per acre. This record is on a picked plot, but the average over the whole area at the present time is probably around 500,000 to 600,000 bbl. per acre.

The magnitude of Baku oil accumulation may be best appreciated if compared with United States standards. The whole producing area of the Apsheron Peninsula is about 12 square miles, or equivalent to 12 sections of Oklahoma or other states. The production of that area reached 100,000 bbl. per day in 1892, and ever since it has been producing in excess of that figure, the present output being 150,000 bbl. per day. For a number of years the Baku fields produced in excess of 200,000 bbl. per day, and that figure undoubtedly will be again achieved by 1930, without any new discoveries. The total recovery cannot be even estimated at this time, because Miocene and Oligocene formations remain yet untested, and if they come up to expectations as much as 5,000,000 bbl. per acre may be taken from the most prolific spots. To reduce Baku fields to Oklahoma standards one would have to imagine a Seminole field with 15 to 20 Wilcox Sand horizons from the surface to 3000 ft., with the deeper possibilities quite as good.

In addition to the Caucasus the possible oil accumulations of Russia are located along the western slope of the Ural Mountains in the Great Permian Basin, where 500 miles is considered a small distance, also in the East Caspian Basin and east into the Central Asia. Oil seepages are known to exist throughout all of the above-mentioned areas and geologically all of the area can be considered as favorably as the southwest Texas Permian Basin. Actual production has been developed so far, from shallow sands in the Emba district on the north end of the Caspian Sea and to a smaller extent in the Central Asia.

Siberia is still a closed book as far as oil is concerned. Seepages are known to exist in many localities.

J. E. Pogue,* New York, N. Y.—This paper contains a wealth of facts which are available from no other source. I suppose it is impossible to estimate the reserves except as brought out as to the magnitude. From my casual reading I have been tremendously impressed with the future of Russia as the resource of oil. Of course Russia in itself will present in the future a very large market for petroleum products and therefore will not be in position to export large quantities on European markets. I realize, however, that the main problem of Russia will be to get the capital to develop its resources.

B. B. Zavoico.—The present estimates of oil reserves in the known fields are: Grozny, in the neighborhood of 500,000,000 bbl.; Baku, about 1,000,000,000 bbl. I believe that the estimate of Grozny's two fields is reasonably correct, but in Baku two to three billion barrels can very well be reclaimed yet, considering the deeper possibilities and more efficient methods of production. In the remainder of Russia the reserves cannot be estimated, but in the region of the Caucasus alone one or two Baku type fields may be opened and 20 or more of Grozny type.

As far as the export markets are concerned Russia is in an exceptional position since gasoline cannot be sold at home in large quantities and no rapid increase in home consumption can be anticipated for many years to come. With the gradually increasing recovery of gasoline from crudes the available supply of gasoline for export trade will be increasing very rapidly, without affecting in any way the structure of home

* Consulting Engineer.

distribution. Therefore it is only logical that the leaders of Soviet oil industry are attempting to enter European markets on a large scale, and their aim may very well be to obtain the control of gasoline markets in certain countries, especially of ones located in the Mediterranean basin, easily reached by tankers from Batum.

L. C. Snider,* New York, N. Y.—Is much difficulty encountered with the water sands in Baku?

B. B. Zavoico.—There is but little water trouble in oil-bearing horizons. There are few sand lenses and beds carrying nothing but water and their exclusion presented difficult problems with antiquated drilling methods, but with modern drilling this difficulty is easily overcome. Some water is associated with oil in oil sands, but both are produced and then separated in tanks.

S. L. Gillan,† Los Angeles, Cal.—Is there an edge water condition at all?

B. B. Zavoico.—Yes there is, but only when one drills away from the main field area.

---

* Geologist, H. L. Doherty & Co.

† Geologist.

Oil Fields of Colombia in 1927

By L. G. Huntley,* Pittsburgh, Pa.

(New York Meeting, February, 1928)

The entire production of Colombia for 1927 was that from the Tropical Oil Co. concession. Production was approximately 14,000,000 bbl., of which 12,081,000 bbl. were exported from the Mamonal terminal of the Andian National Corp. near Cartagena. The balance represents that refined and used or marketed within Colombia.

As production in 1926 was only 6,443,540 bbl., the increase has been more than 100 per cent. This is partly due to the looping of the pipe line from the concession to the coast, and the resultant increase in capacity to 50,000 bbl. per day, and also to increased domestic sales. The refinery at Barranca has been doubled in capacity, and it is understood is now handling 5000 bbl. of crude daily. This gives the producing field a potential outlet of 55,000 bbl. daily. The Tropical Oil Co. completed 82 wells in 1927, with one abandoned for drilling difficulties. The average daily initial production was 1136 bbl. per well. The largest well is reported to be No. 173 La Cira, rated as 5000 bbl. initial. Most of the wells were drilled on the Infantas and La Cira structures, the latter located en echelon to the northwest of the main Infantas anticline, and separated from it only by a low saddle. Drilling operations on the Llanos fold, also en echelon with Infantas but to the southeast, and at San Luis, bearing about the same relationship to the Umir Hills uplift, are still more or less in the exploratory stage.

The four structures mentioned cover approximately 15,000 acres, on which there are at present 223 producing wells. Drilling has been better than 92 per cent. successful since starting operations on this concession. Allowing 15 acres per well, which is 50 per cent. more than good practice in the Mid-Continent fields, there is thus room for 1000 wells, which at the recent rate is a 10-year drilling campaign. This does not take into consideration the known deeper oil zones, which have not been prospected, but which are uniformly petroliferous at their outcrops to the eastward.

It is estimated that with the enlarged pipe line capacity, as well as increased domestic consumption, the production for this country will be about 20,000,000 bbl. for the current year of 1928. It is possible that

* Consulting Geological Engineer, Huntley & Huntley.

if opened up the field could produce approximately 150,000 bbl. per day. The employes' strike at Barranca was settled early in 1927.

No other production was developed elsewhere during the past year. The Standard Oil Co. (California) is drilling three wells along the coastal belt. The Gulf has one well standing idle on the Colombia Syndicate properties in the Lebrija district; is drilling one well on the Leonard property, and clearing and road-making for two more on this latter property east of Puerto Wilches. The Lobitos Oilfields are drilling one well on the Cortizos property northeast of Infantas. This Scotch-English group operates the Lobitos property in northern Peru, adjacent to the International holdings, and sells its production to the International. It is reported to hold a large block of Tropical Oil Co. stock.

Legislation

The Colombian Congress attempted to pass a new petroleum bill during the latter part of the year. This was written much in the spirit of the petroleum legislation of Mexico during recent years, and was in certain of its provisions probably inspired from that source. The bill failed of passage, and was carried over until the present year, but an emergency bill was passed during the last days of the session, which, if it should be embodied later in the laws of Colombia, will stop exploration work on the part of those companies already in the country and deter any newcomers. In several specific instances this has already been its effect. The provisions of this Emergency Bill have been summarized by O'Shaughnessy as follows:[1]

Article 1. Establishes the ownership in the nation of Tierras Baldias (unsurveyed public lands), including "any reversions of any nature." This latter is no doubt intended to include the Barco concession, and any lands title to which the Government may consider unsatisfactory.

Article 2. Extends the period from four to six months for oil companies to present title documentation "demonstrating ownership" of lands being explored under lease or held by concession.

Article 3. Declares all denouncements or contracts, etc., referring to oil lands depending in the Ministeriat of Industries, to be suspended unless contract be approved by Congress. This provision permits of the ratification of the Yates contract. Pending the passage of a petroleum law, exploration may be carried on "under such terms as the Government may fix."

Article 4. Reserves the exclusive right to the Republic to construct pipe lines, provided however, that contracts may be made for this purpose with companies or individuals, with the approval of Congress.

The Tropical Oil Co.'s concession is practically the only property which will not be affected by the new legislation.

---

[1] *O'Shaughnessy's South American Oil Reports* (Nov., Dec., 1927). See also Yates contract.

The companies drilling in Colombia on leased properties, titles to which are anterior to 1873, and hence by law include subsoil rights, are Gulf Refining Co. (Mellon interest), Standard Oil Co. (California), Leonard Oil Co., Colombia Syndicate, Magdalena Syndicate, Lobitos Oilfields, and Transcontinental Oil Co. (Benedum & Trees).

The essential features of the emergency bill are (1) the ratification of the Yates contract; (2) the building of a refinery for government royalty oil, and (3) to extract from the owners of private lands or their lessees (oil companies) an additional 10 to 20 per cent. royalty. To the extent that this bill is retroactive it is confiscatory in the same manner as certain Mexican legislation.

In this connection the author believes it best to quote from Mr. O'Shaughnessy.[2]

"Cable resume is received of Reglamento No. 150 to Law 84 of 1927 (so-called Emergency Petroleum Law), signed by the Minister of Industries and the President of the Republic, and became operative Jan. 30, 1928. The effect of this regulation is to lodge in the Minister of Industries absolute control of petroleum development of Colombia through the power fixed in him to grant or withold permits to drill. All companies or individuals now holding petroleum property, in applying for such permits, must present to the Minister proof of title, satisfactory to him. No legal procedure is prescribed to govern his decisions, nor is any time fixed during which he must act. It is a well-known fact that in almost every instance it is impossible for landowners to furnish to the Minister proof of title to which he could not find objections. As this reglamento provides that if proof of title satisfactory to the Minister is not furnished, the lands involved revert to the Government unless and until the Courts decide otherwise, it is plain that it lies within the Minister's power to declare all petroleum lands as the property of the Government. This does not affect the Tropical Oil Co. which is operating under a signed contract with the Government. Under this reglamento it is practically impossible for any of the oil companies to proceed with development in Colombia."

Internal Development

Colombia is the only South American nation whose territory is comparable (area for area) with that of Mexico, for the variety and richness of its natural resources. Like Mexico, its capital and ruling class is located within the mountainous interior of the country. Naturally enough, such groups often have a provincial point of view, combined with jealousy and fear of outside influences. Of recent years Colombia has made great strides in internal development and the future seemed to hold promise of a gathering momentum in that direction. It is to be hoped that more liberal views will in the end govern their attitude toward those whom they are inviting to invest capital within their boundaries. It would be a pity should the potentially richest country bordering on the Caribbean decide by its actions to retain a medieval status. Meanwhile Venezuela, with fewer natural resources, is going ahead by leaps and bounds, and has

[2] *O'Shaughnessy's South American Oil Reports, Bull.* 132 (Feb. 3, 1928).

already passed Mexico's rate of oil production, which it may soon double.

Production in Colombia since the beginning of exploitation is as follows: 1923, 424, 000 bbl.; 1924, 500,000 bbl.; 1925, 500,000 bbl.; 1926, 6,000,000 bbl. (pipe line finished in June of this year); 1927, 14,000,000 (estimate).

In 1926 publicly offered American loans to Colombia were $28,320,000, and in 1927 were $53,200,000. About $120,000,000 of American currency is invested in private enterprises in that country. We buy 80 per cent. of all her exports, and in turn sell 50 per cent. of all her imports; which business in 1926 amounted to $140,000,000; comment is almost unnecessary.

One of the most interesting phases of oil intrigues in Colombia during the past year was the appearance of a large corps of geologists under the aegis of the Anglo-Persian Oil Co. Shortly thereafter an attempt was made to secure a blanket concession upon all Federal reserve lands, which under the proposed law would include the Barco concession as well as many privately owned lands whose subsoil rights were to be cancelled under retroactive legislation. Apparently failing in this effort, negotiations of a similar nature were carried on by H. I. F. Yates of London, whose principals were obviously the same Anglo-Persian Oil Co. The Emergency Petroleum Bill allows for the ratification of a large concession around the Gulf of Darien at the mouth of the Atrato River, to Mr. Yates but reading between the lines of its provisions one is led to suspect it is intended to cover all national lands. As the Anglo-Persian Oil Co. is partly owned by the British Government, and as Mr. Yates' negotiations apparently dovetailed with certain British mining claims sponsored by that Government,[3] and as this concession is very close to the Panama Canal,[3] the possibilities of future interesting developments are very good.

A bit of irony is brought into the situation involving the Barco Concession, in this way:

"Colombia's representatives before the Swiss Boundary Commission included in their argument for fixing the boundary between the two countries, so as to take in the Barco concession, that General Barco, a Colombian citizen, had discovered and refined oil on what is known as the Barco concession. This was considered as evidence sufficient to include the area in Colombia. The Colombian Government in cancelling the Barco concession, denied that work had been done on the area by Barco's assignees, which they claimed before the Swiss Commission had been performed. Consequently they are in this dilemma: if the Colombian Courts uphold the Government in its cancellation of the Barco concession, the Venezuelan Government will likely reopen the Boundary question."

The author is indebted to Michael O'Shaughnessy for help in the preparation of this paper; particularly for recent developments since the former's trip to Colombia early in 1927. He has drawn freely from data

[3] *O'Shaughnessy's South American Oil Reports* (December, 1927) 4–7.

contained in *South American Oil Reports*, as well as personal communications from Mr. O'Shaughnessy.

DISCUSSION

S. L. Mason, Pittsburgh, Pa.—What is bad news in other countries is apparently good news in Colombia. It is true production increased 100 per cent. this year, but the Government is doing all it can for us by discouraging oil production. So far as the oil situation here is concerned, it is good news from Colombia.

The only producing history is that of the DeMares concession of the Tropical Oil Co., and some of the figures which Mr. Huntley presents are very interesting. There are four structures and of the 100-and-some wells, 92 per cent. have been successful since the start, allowing 15 acres to the well, which is a considerable increase over the Mid-Continent practice. There is room for 1000 wells, and the Tropical concession seems to hold considerable promise for the company.

The greater part of Mr. Huntley's paper is taken up with discussion of the recent legislation in Colombia, and there are rumors and a great many people seem to be well satisfied that the inspiration for this legislation came from Mexico. I do not know their reason for wishing to have production fall off as Mexico's did.

One point of interest is the dropping of negotiations with the Anglo-Persian Oil Co., which happens to be one of the only oil companies of any size, which is more than owned by a government. It was found that legislation on zoning, enacted years ago, specifies that no concessions within the outer zones could be held by companies having any government connections, that is with foreign governments. Negotiations with the Anglo-Persian Oil Co. were dropped and since then negotiations have been carried on with Colonel Yates, who apparently is—he used to be—manager for the Anglo-Persian Oil Co. It is the sort of thing we have to expect, but it does not seem as though it would be wise to encourage it.

F. O. Martin,* Los Angeles, Cal. (written discussion).—It seems to the writer, who has lived for the greater part of 1920 to 1926 in Colombia, that a fair petroleum law will not be enacted until competition for possible oil lands for development has ceased for a number of years. Most of the large American oil companies have shown no interest in government lands under existing laws, but some have leased lands with titles antedating 1873, and at least one large oil company has bought lands outright with titles antedating 1873. It seems now that development of such lands, either leased or owned, will also be interfered with by the recent government regulations. These regulations affect both Colombian and foreign landowners since some progressive Colombians have spent their own money in having foreign (German) geologists prospect for oil, and, having found it, have made applications for permits to exploit under existing laws. Now that these Colombians are also tied up, it is but natural that strong opposition to the latest regulations have already developed.

If it had not been for foreign capital and the exploration trips of foreign geologists, no oil development whatever would have taken place in Colombia and Government revenues would be much less. It does not seem to be appreciated or understood that many improvements (such as road building), necessary before drilling can be started anywhere, would also benefit the inhabitants. So far Colombia has only benefited from all oil companies since only the Tropical Oil Co. has taken anything out of Colombia, whereas all the others have spent great sums in the country. It seems to me a very inopportune time for legislation such as recently enacted, with the present supply of oil and the likelihood that it will continue for some time.

---

* Geologist, Union Oil Co. of California.

Review of Petroleum Production in Countries Other than United States, Russia, Mexico, Venezuela, Colombia and Peru

By J. T. Duce* New York, N. Y.

(New York Meeting, February, 1928)

In viewing the petroleum world as a whole certain tendencies are to be noted. The first of these is of a legal and political nature. It involves the nationalization of the oil industry; in some instances going into all its phases and in others with reference simply to production.

Table 1.—*World Production*

In Thousands of Barrels

	1924	1925	1926	1927
United States	713,940	763,743	770,874	905,947
Russia (not including Saghalien)	45,312	52,448	62,941	76,140
Persia	32,373	35,038	35,842	41,975
Mexico	139,497	115,515	90,421	64,367
Venezuela	8,754	19,687	37,381	64,000
Rumania	13,303	16,646	23,292	26,356
Dutch East Indies	20,473	21,422	20,817	22,715
Colombia	445	581	6,444	13,000
India	8,150	8,000	8,270	8,250
Japan and Formosa	1,959	2,000	1,557	1,750
Saghalien				350
Peru	7,812	9,164	10,782	11,000
Poland	5,657	5,960	5,844	5,195
Argentine	4,669	5,818	7,947	8,000?
Trinidad	4,057	4,654	4,947	5,200
Egypt	1,122	1,226	1,181	1,150
Sarawak	4,163	4,257	4,942	5,120
France	426	459	478	440
Czechoslovakia	75	158	150	150
Germany	406	411	653	700
Canada	164	318	365	486
Italy	45	45	30	25
Ecuador				506
Other Countries	125[a]	125[a]	475[a]	300
Total	1,012,927	1,067,675	1,095,633	1,263,122

* Geologist, The Texas Co.

[a] Includes Ecuador.

Regarding production itself, we note general increases throughout the world with two or three exceptions. (Table 1.) The most interesting news of the year is that emanating from Iraq where the Turkish Petroleum Co. has discovered oil in large quantities apparently from the same horizon which has been so productive in Persia. One of the wells, that at Baba Gurgur, produced 95,000 bbl. of light oil, 34° (A. P. I) in 24 hr. Undoubtedly a new producing area of great importance has been developed and will have its effect on the world market.

Notable increases have also been made in Rumania, Russia and the Dutch East Indies and it is believed that the development in these countries presages further increases during the coming year. The Rumanian increase is due to the development of the prolific Meotic sand around the Moreni dome. Russia has shown steady progress and there are recorded at least two new fields in that country. With the number of wildcat wells drilling additional fields should be discovered within the coming year.

In Borneo the discovery of deep production at Tarakan presages additional development in the Dutch East Indies and it is interesting to note that the Kolonial, a subsidiary of Standard Oil Co. (N. J.), has now a production there of over 1,000,000 bbl. per year.

The falling Japanese production was somewhat stayed by the discovery of some new production in Formosa and it is also interesting to note that Japanese companies now have 1600 bbl. a day in Saghalien.

Of minor interest is the rise in the German production and the development of the new Oberg field. The coming year will see the first large scale Bergius plant in operation there. It will produce 100,000 tons of motor fuel per year.

No great change is noted in South America outside of Venezuela and Colombia.

Large declines in production were noted only in Mexico with small declines in India, Poland and Egypt. Several changes in the order of importance occurred. Russia takes the place of Mexico in second, Mexico falling to third, Venezuela remains in fourth place but will displace Mexico in third during the coming year. Persia remains in fifth place and Rumania and the Dutch East Indies in sixth and seventh. World production for 1927 reached 1,260,000,000 bbl. and for 1928 will probably increase an additional 3,000,000, the decline in Mexico and the United States being offset by increases in Venezuela, Colombia, Russia, the Dutch East Indies and Rumania.

In respect to legislation, it is the writer's belief that the high tide of restrictive legislation has passed with the year 1927, and that more sane views of the oil industry will mark the coming year. The main functions of the industry are to provide cheap sources of power and lubrication to the world and are too often lost sight of in political discussions. Exces-

sive taxes, high customs barriers, monopolies, restrictive laws and all regulations tending to obstruct the free development of petroleum lands and the flow of petroleum in trade are reflected in the prices paid by the people at large for petroleum products in the country in which these regulations are adopted. There is a golden mean between restriction and regulation too seldom recognized. A large part of the present monopolistic and restrictive tendencies can be traced to a lack of knowledge of the petroleum industry and its workings. Writers who know little of the industry have capitalized its errors and have introduced oil into politics to the detriment of both politics and oil.

In preparing a paper of this type, one is immediately struck by the poor facilities for the gathering and dissemination of petroleum statistics in countries other than the United States. Excellent statistics are available in some countries: Russia, Rumania and Mexico. Of the other countries little is known and it is difficult to secure adequate data on which to base estimates on supply and even more difficult to find data on demand. It would be desirable if there were some central international agency to collect and disseminate statistics regarding the industry as a whole, particularly, regarding supply and demand. The petroleum reserves of the United States have been fairly well estimated by geologists and engineers but the estimates for foreign countries are probably far astray. Much could be done to simplify the international situation if better estimates of reserves were available and possibly good estimates might be of much importance in the easing of international friction which has resulted from the struggle for petroleum reserves. No extensive development of production, no matter how remote, but has its effect on the world situation. Increase of production in Russia causes Trinidad and Venezuela to send a larger proportion of their production to the United States. Overproduction in California affects the price of kerosene in Borneo. Huge production in Iraq will have almost as much influence on the price of gasoline in Tulsa as overproduction in West Texas. The following notes give some of the interesting development during the year.

North America

Canada

Canadian production increased during the year. The chief source of the increase was the Turner Valley field where there were 979 bbl. a day of naphtha production from 8 wells and 455 bbl. a day of light crude during the month of December. Royalite 4, the discovery well, in the Madison limestone still continues the largest producer. All the naphtha production comes from this horizon and the light crude from the Dakota and Fernie. A second commercial field producing heavy oil from the

Ellis has been discovered by the Devenish Petroleum Co. near Skiff, Alberta. This well made 250 bbl. on pump. Small production of heavy oil has been the only result of the campaign at Irma-Wainright.

In eastern Canada the Henry L. Doherty interests abandoned their deep hole at Prince Edward Island without finding production but are planning to drill another test on Pictou Island, Nova Scotia.

Production for the year is estimated as follows:

	Bbl.
Alberta	295,000
Ontario	135,000
New Brunswick	56,000
	486,000

West Indies

Barbadoes

Small production (5000 bbl. a year) is still won from shallow wells. Two deep tests drilled in 1926 failed to find commercial production.

Cuba

Small light oil production continues and is estimated at 5000 barrels.

Dominican Republic

The Texas Co. is drilling a well near Azua. This well was drilling at 1700 ft. with no commercial production encountered to that depth.

Trinidad

Production in Trinidad increased slightly in 1927; being estimated at 5,200,000 bbl. for the year. The largest producer was the Apex-Trinidad and the second Trinidad Leaseholds. The production for 1926 was 4,947,000 bbl. Increased activity is expected as soon as the Government leases additional tracts of Crown lands.

South America

Bolivia

No further news of importance has developed in Bolivia since the Standard Oil Co.'s discoveries in 1926. No detailed account of the Standard's operations is available but it would appear from scouts' reports that they have developed at least two fields of commercial consequence; one of these along the Bolivian-Argentine boundary and another one somewhat further north. The Standard is at present drilling 10 wells in southern Bolivia.

Production for the year is estimated at 5000 bbl., used mainly for fuel purposes.

Announcement was made in the latter part of the year that a concession of 30,000,000 acres of land in the Bolivia Choco had been granted to the Bolivia Concessions, Ltd., which proposes to colonize and develop this property for oil and for agricultural purposes.

Brazil

Brazilian papers carry from time to time reports of activities in Sao Paulo where drilling in the Permian has resulted in the discovery of small oil and gas shows. No production in commercial quantities has yet been uncovered. A project for a new petroleum law was placed before Congress in July. This legislation if passed tends to nationalize the petroleum industry.

Chile

No production is recorded from Chile during the past year. Examination of an area about Antofagasta was undertaken by an Australian company. Oil shales found on the Rio Bio River have excited the interest of Chilean capitalists. The oil lands of Chile were nationalized under an Act which declares all concessions cancelled if not developed by Dec. 26, 1927.

Ecuador

The Anglo-Ecuadorian Oil Co., Ltd., has made very considerable progress during the year. The record of its production up to October is given below:

January	4457	June	4734
February	3717	July	5001
March	4711	August	5769
April	4450	September	6470
May	4757		

Production for the year is estimated at 505,998 bbl. Both the South American Gulf Oil Co. and the Standard Oil Co. (Calif.) ceased operations in Ecuador during the year.

The Guianas

No development has taken place in the Guianas during the past year. Geologists have examined the area along the Barima River in British Guiana for an American company.

Paraguay

Newspapers carried notices regarding a dispute between the Bolivian and Paraguayan Governments over prospective oil lands in the Chaco.

Central America

The only important operation in Central America during the past year has been that of the City Fuel & Power Co., which is drilling a second well in the Chucunque Valley in Panama. Its Yape 1 had gas and salt water at 3500 ft. No. 1 Capeti was junked at 1000 ft. and No. 2 is now drilling at below 2600 ft. If oil is to be found in southern Central America it should be found in this district and the results of these tests are awaited with interest.

In the rest of Central America the only activity noted is the drilling of a well by the Perpetual Petroleum Corpn. in the Province of Izabel, Guatemala. This well is now shut down at approximately 80 feet.

Europe

Albania

In Albania small production has been found in several wells which are: Italiana delle Minere de Selenetza Penkova 1, 70 bbl. at 1800 ft.; D'Arcy Exploration Co., Berat 1, 500 bbl. heavy oil at 900 ft., and Ardunitza 1, gas at 3500 feet.

Bulgaria

Activity in securing concessions has been shown about Kasenlik on the north side of the Marica Valley where a light oil seepage has been found.

Czechoslovakia

Production for the year is estimated at 150,000 barrels.

England

Production from England for the year is estimated at 1000 barrels. The Broxburn Co. closed its shale refinery at Albyn.

Esthonia

Fuel oil continues to be suppied from oil shale in Esthonia. Concessions for development of Esthonian shale land have been granted a Swedish company.

France

The year 1927 brought no new developments of consequence in France. Production was 440,000 bbl. for the year. In southern France at Gabian in the department of Heroult the Government was drilling on its 26th well on June 1. Five wells have been successful and these five are now

averaging less than a barrel a day each. Of the wells the following are the production records up to June 12, 1927:

	Tons	Bbl.
1	1,164	8,228
4	1,959	14,550
6	5,170	38,410
15	755	5,608

Production for the year from the district will be under 1000 tons. Drilling up to June had reached 4786 meters and for the year 1927 will be 2400 meters.

In Alsace production of oil from mines continues and will reach about 400,000 bbl. for the year.

The production from oil shale is about 35,000 bbl. per year.

Much prospecting activity has been evident along the foot of the Pyrenees but as far as the writer knows none of it has ripened into drilling.

France has been very active also in the search for gasoline substitutes and engines have been developed to run on gas from the distillation of wood. Coupled with this has been much political activity including many projects for national monopolies. There has been manifested besides much anxiety over the possible supply of oil in case of war. In view of the geological conditions in France, it seems reasonable to suppose that production might be developed if suitable legislation were enacted to encourage prospecting. The present requirements of France are about 18,000,000 bbl. per year.

Italy

The National Petroleum Bureau (Azienda General dei Petroli) is making a survey of Italy for oil. The production mainly from the Emelia district is estimated at 25,000 bbl. Some progress is being made in the distillation of lignites for motor fuel by the Soc. Benzonaftene at Sesto San Giovanni near Milan.

Germany

The development of the Hanover salt domes has continued throughout the year. Production is still being secured from the Nienhagen salt dome and development is also taking place in the Oberg pool in Hanover where the present production is running about 7000 bbl. a month. Production for the year from Hanover will probably reach the figure of 700,000 barrels.

The Oberg production in contrast with Nienhagen comes from a relatively shallow depth of from 200 to 300 meters and is produced from the sand stone in the Liassic shales. The oil is a gravity of 31° A. P. I. and produces 25 per cent. gasoline upon straight run distillation.

We may expect that Germany in the future will produce more and more oil from around its salt domes as development proceeds. A search for gas is now being made at Neungamme near Hamburg where gas was struck in commercial quantities in drilling for water in 1910.

Unfortunately I have no figures for the amount of oil produced from lignite by carbonization, however, during the coming year the Leuna organization of the I. G. Farben industrie will go into production and it is estimated will produce 100,000 tons of motor fuel per year from the hydrogenation of coal.

Poland

Production in Poland declined for the year. Production, however, has been found in the Boryslaw sandstones in the southern end of the Mraznics district and the development there may affect production for the coming year. The Boryslaw Tustanowice field continues to produce the larger part of Poland's oil. Improvements are noted in producing methods and the utilization of gas. About 50,000 bbl. of natural gas-gasoline were extracted by 16 plants. Production for the year is estimated to be 5,195,000 bbl. distributed as follows:

Districts	Bbl.
Cracow	200
Vaslo	564,000
Drohobyez	4,316,000
Stanislaw	325,000

Exemption from all direct taxes was given by the Ministry of Industry and Commerce to all companies who are engaged in exploratory work, in order to encourage the exploration for oil in Poland.

Rumania

In Rumania the petroleum industry is still in a state of flux. Hampering legislation has combined with inadequate transportation facilities to hold back development. Nevertheless, the discoveries in the rich Meotic sand about the Moreni Dome, combined with an intensified drilling program have resulted in a very considerable increase in Rumanian production. It is estimated at 26,356,000 bbl. for the year against 23,292,000 for 1926. A further increase is expected for 1928.

It is probable that deeper sands will be found about the Rumanian salt domes. Improvement in producing methods has been notable, particularly in controlling the large wells for the Meotic sand. Rumanian wells are now equipped with heavy control valves and the usual "Christmas tree" so that it is now the exception, rather than the rule, to have big wells get out of control.

Production of Petroleum in Rumania, 1924–1927

		1924	1925	1926	1927
By years, bbl.*		13,303,000	16,646,000	23,292,000	26,356,000
	Prahova	Dambovita	Buzau	Bacau	Maramures
By districts in 1927, bbl.*	17,652,000	7,396,000	840,000	468,000	50
		1924	1925	1926	1927
Meters drilled		166,936	204,407	268,000	325,000

* Barrels of 42 gal. each.

Number of wells as of Sept. 30, 1927:

	Hand Dug			Drilled Wells		
	Digging	Producing	Abandoned	Suspended	Drilling	Producing
Prahova	263	47	139	460	466	973
Dambovita	4	17	17	15	75	114
Buzau		20	5	18	14	111
Bacau		179		50	13	123
Maramures	2	2	7	5	6	

Of the companies, Astra-Romana (Royal Dutch) will be the biggest producer for the year with about 4,300,000 bbl. followed by Creditul Minier with about 4,000,000, Steaua Romana, Phoenix Oil & Transport, and Romana-Americana following in the order named. Exports for the year, practically all of refined products, were approximately 12,000,000 barrels.

Switzerland

The deep test at Lintheban has stopped at 3300 meters.

Spain

The Spanish monopoly went into effect Jan. 1, 1927. By its terms the Spanish Government takes over control of the industry and acquires wide powers to sell, manufacture or prospect for oil.

Africa

Algeria

Production for the year from Algeria was 9000 barrels.

Angola

The Sinclair Exploration Co. has continued its drilling campaign without discovering commercial production.

Congo

Oil seepages have been found in the Kilo Moto district of the Belgian Congo. This is on the shore of Albert Nyanza.

Egypt

The production for the year was 1,150,000 bbl. mainly from the Hurghada pool. A progressive increase in the amount of production of the Anglo-Egyptian is to be noted. This in the main is due to the increase in efficiency of the dehydrating plant recently installed at Hurghada. It is also announced that this company has taken a lease on the Farsan Islands in the Red Sea, where it will operate as the Red Sea Petroleum Company, Ltd.

Madagascar

The exploration of the tar sands of Madagascar is being continued by French geologists.

Portuguese East Africa

The Inhaminga Petroleum, Ltd., is drilling near Inhaminga. No. 2 well was last reported as gassing from 1188 ft. The No. 1 well was abandoned at 1270 feet.

Uganda

It was announced that the Anglo-Persian would make a geological survey of Uganda for the purpose of ascertaining if oil occurs in commercial quantities.

Union of South Africa

Continued discussion of the possibilities of obtaining oil from beds of Karoo age appears in the South African papers. The Devon Prospecting Syndicate reports shows of oil in a well drilled 65 miles southeast of Johannesburg.

Australia

The search for oil in Australia continues but no commercial production has as yet been found. The South Australia Wells Co. was drilling at 115 ft. The Roma Oil Corpn. is drilling below 3555 ft. near Roma. At Newnes the Commonwealth Oil Corpn. has closed down the shale oil works.

New Zealand

The campaign for production continued throughout the year. The Taranaki Oil Field, Ltd., abandoned its Terata and Moturoa wells. The latest report gives the following: No. 2 Waiapu gassing at 1919 ft.; No. 1 Gisborne drilling at 75 feet.

East Indies

New Guinea

Further attempts to discover oil in New Guinea have not yet resulted in commercial production of consequence. The Anglo-Persian has under-

taken to make a survey of Papua for the Commonwealth Government. The New Guinea Oil Co. announced that it had gas accompanying water in its wildcat well. The gas pressure was 250 lb. at a depth of 1335 feet.

Timor

The Timor Petroleum Co. has a small well (10 bbl.) at 295 feet.

Australasia

Dutch East Indies

Production is increasing in the Dutch East Indies, being estimated at 22,715,000 bbl. for 1927 in contrast to 20,814,000 bbl. in 1926. The increase is attributed to: The activities of the Kolonial (Standard Oil Co. of New Jersey) in Palembang, Sumatra; greater activity by the Shell in Palembang, Atjeh and Djambi; the discovery of deep production at Tarakan, where a deep well came in late in 1926 flowing 3400 barrels.

Production continues to decline in Ceram and Java.

In general we may expect a continued sustained production in the Dutch East Indies, which will be maintained by deeper drilling and further exploration. Production for the year is estimated as follows:

	Bbl.
Sumatra	6,122,000
Ceram	40,000
Tarakan	6,424,000
Borneo	8,760,000
Java	1,369,000
	22,715,000

Asia

Burma

Production for the year was maintained in Burma; it was estimated at 8,100,000 bbl. (This figure includes India.) The largest producing field was Singu where production is increasing as this pool has not yet reached its peak. Yenama may also become important in the near future.

It is interesting to note the opinions of two English geologists with reference to Burma. Sir Thomas Holland says in the *Daily Telegraph*, London, for May 25, 1927:

"Apart from proving and development of Yenangyaung oil field to extent that it is now known, the Burma Oil Co., Ltd. brought in the Singu field of Burma and there is scarcely a potentially petroliferous area, however remotely so, in the province or in the whole Indian continent which has not at some time been examined and mapped by the large and highly trained staff of geologists which the company has maintained for almost a quarter of a century and hundreds of thousands of pounds have in the period been expended in putting the most promising of these to test."

Dr. Murray Stuart commenting in the *Petroleum Times* for June 4, 1927, on the pronouncement states that if all this is true it would appear that the writing is on the wall for Burma unless it (The Burma Oil Co., Ltd.) can discover new and undiscovered valuable petroliferous areas, and concludes his article by the following:

> "It is now obvious . . . that there are almost certainly other, but, concealed fields, which there is no reason to suppose may not equal Yenangyaung and Singu in value. The future of the oil industry in Burma, therefore, is dependent on exploratory drilling. The companies that accept the view that everything likely to be valuable has already been investigated will decline as the production of the existing Burma fields declines, whereas the company which boldly investigates and obtains a new concealed oil field in Burma will have a big future before it. The chances are good and the alternative to making the attempt is to die slowly of inanition. Which company is going to make the effort?"

The writer, from his small knowledge of the situation, is inclined to agree with Dr. Murray Stuart and in this connection it was interesting to note that during the year the Indo-Burma Petroleum Co. brought in a big gas well (said to be the largest in the world) at Peikthalein in the Thayatmyo district. Much progress has been made in increasing the efficiency of producing operations in Burma.

Iraq

The most important development of the year, from a producing standpoint, is the discovery of new production in Iraq. The Turkish Petroleum Co. started drilling 10 wells during the year at the following points in the villayets of Bagdad and Mosul (Fig. 1): Khashin, Palkhana No. 1, Injana, Palkhana No. 2, Tarjil, Baba Gurgur, Jambur and Gaiyara. The remaining two of the first 10 test wells are to be at Khormor and Khanupay. The first oil in these wells was struck at Palkhana where a 100-bbl. well was found at 65 ft. and later at 1320 ft. a 200-bbl. well was secured. Palkhana No. 2 also found oil at 1260 ft. and produced at the rate of 700 bbl. a day but this has mudded off and the well is now drilling deeper. At Baba Gurgur a well to the Ashmari limestone came in on Oct. 14, 1927, flowing at the rate of 95,000 bbl. a day of 37.4° A. P. I. oil, with a rock pressure of 270 lb. The Gaiyara well is said to have passed through three sands, all of which are rated at 5000 bbl. a day. The oil here had a gravity of 22° A. P. I. The Injana well is also reported to be showing for big production.

Plans are being made for a survey of a pipe line from Iraq to the Mediterranean coast.

These large wells brought in in Iraq during the past year are the introductory phase of another series of flush fields similar in type and content to those of Persia and Mexico. The production is from limestone. The

formation which is productive extends in general from Baluchistan northward to the Villayet of Mosul in Iraq.

It is also to be noted in connection with Iraq that the Anglo-Persian Oil Co. has a large field already partly developed in the Transferred Territories at Khanikan. A refinery has been constructed to supply oil to northern Persia and Iraq in competition with the oil from the Baku district. From the meager field reports we have, this field is one

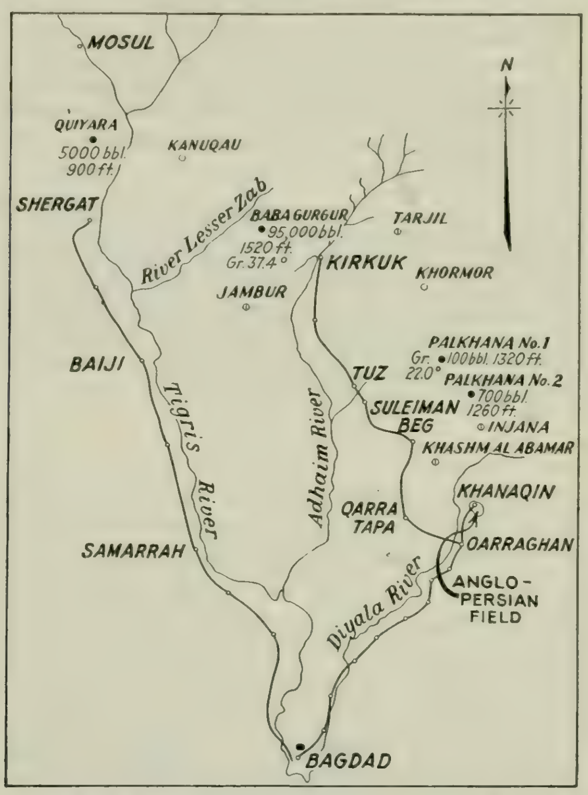


Fig. 1.—Map of part of Iraq, showing location of first 10 test well of Turkish Petroleum Co.

of major dimensions. The construction of a pipe line to the Mediterranean will bring to the Mediterranean countries a new and important supply of oil to compete with that from Russia and Rumania.

Japan

Japanese production continues to decline except for Taiwan, where, at Boryitzu, a 200-bbl. well was brought in early in the year. The year's production is estimated at 1,750,000 bbl. in contrast with 1,557,000 for

1926, the increase coming from Formosa. The hope of Japan for future oil supply lies in the Saghalien concessions and Formosa. It is doubtful if developments outside of these two areas will more than stay the declining Japanese production.

Manchuria

The Manchurian Railway has discontinued its experiments on oil shale.

Persia

Persian production continued at 115,000 bbl. a day and the production for the year is estimated at 41,975,000 bbl.

No material increases in production may be expected from Persia except upon the completion of more facilities and the discovery of additional fields. The Anglo-Persian Oil Co. has been exceptionally active in the last year in geological work and has employed not only field geologists but the torsion balance, the Schlumberg electrical method, the magnetometer, and the seismograph, in the exploration of prospects. In a recent book[1] it is stated that in Masjide-i-Sulheman field the oil water level is constant and that the Anglo-Persian Oil Co. is considering the possibility of introducing water at the base of the dome to flush the producing horizon. The rock pressure in the main field has been falling steadily until the last year, when the precautions taken by the Anglo-Persian have resulted in a marked flattening of the pressure loss curve. It would appear that there is an important fundamental difference between the occurrence of oil in Persia and the occurrence in the Mexican fields. The hydrostatic head of salt water that exists in Mexico is apparently not present in Persia.

Saghalien

The Japanese have had success in developing production in Russian Saghalien; the daily production reaches 1600 bbl. per day from 13 wells with 10 wells drilling. Estimated production for the year was 350,000 bbl. Substantial increases in production may be expected from Saghalien in the future.

Sarawak

The production for 1927 in Sarawak is estimated at 5,100,000 barrels.

DISCUSSION

F. O. Martin,* Los Angeles, Cal. (written discussion).—From what I saw in Germany in 1922 and in 1926, the situation there may be best summed up along the lines indicated by Dr. W. Kauenhowen in a recent paper:[2] lack of systematic exploration

---

[1] J. W. Williamson: In a Persian Oil Field (1927) Benn, London.

* Geologist, Union Oil Co. of California.

[2] Dr. W. Kauenhowen: Pumpen und Brunnenbau, Bohrtechnik (1927) Nr. 20/22.

caused principally by the division of properties in many small tracts. Differences of opinions by German geologists about stratigraphy and tectonics of the probable oil territory. Drilling has not been carried on deep enough in most places. Salt domes, where proved, are insufficiently drilled up. Prospecting by geophysical means may prove salt domes heretofore unknown. Production may be increased by methods used now in the United States, such as better conservation of gas and use of compressed air. Extension of the mining of oil, which is carried on successfully in the Pechelbronn, Alsace field. Need for greater cooperation among technical and scientific institutions and among oil companies themselves in exchanging knowledge gained from experience. Improved control of the exclusion of water from the oil-bearing sands. In most German states the landowners have no subsurface rights and the respective governments may lease the subsurface to third parties. In Prussia the landowners have subsurface rights and community leases are necessary to invite capital to do systematic work.

I agree with Mr. Duce that production in Germany will continually increase because I believe that the drawbacks cited will be obliterated in the near future.

PETROLEUM ECONOMICS

The Trend of the Petroleum Situation

By Joseph E. Pogue,* New York, N. Y.

(New York Meeting, February, 1928)

The past year in the petroleum industry was one of overproduction, rising inventories, low prices, and meagre to vanishing profits. This outcome was the result of a long period of intensive and uncompensated effort on the part of both financial and industrial interests, to stimulate *supply* on the theory that the primary problem facing the petroleum industry was the development of an adequate reserve of raw material to protect a large and ever-growing investment. The stimulus was applied in various forms and through diverse channels: capital had long flowed into the industry in excessive amounts under the attraction of large expected profits; the price level for crude petroleum had persistently been influenced by speculative considerations, with the result that prices declined slowly in periods of flush production and were quick to advance in anticipation of statistical improvement, thus maintaining a superfluous degree of stimulus on wildcatting and on drilling; speculation in inventories had led to the unsound, or at least unusual, business practice of accumulating huge stocks of oil; and, above all, the industry had directed the potent force of technology to the expansion of supply and achieved radical results in accelerating oil discovery, speeding up the rate of oil extraction, and enlarging the recovery of gasoline and lubricating oils from the raw material. In short, the economic conditions of 1927 were exactly those to which the objectively driven enterprise of the petroleum industry had long been directed; and the undesirable financial consequences arising therefrom reflected no lack of success in what had been set out to be achieved, but rather the failure to have established concurrently the necessary means of economic control to prevent the immediate conversion of reserves into current supply, and likewise the oversight in neglecting to apply the technological force to the enlargement and diversification of the market for petroleum products. Perhaps, when viewed in its longer perspective, 1927 will stand out as the turning point in the economic policy of the petroleum industry, when the technique of rationalizing production made its initial claim for recognition.

---

* Consulting Engineer.

Change in Stocks

The outstanding statistical feature of 1927 was an increase in stocks of all oil of approximately 64 million barrels, compared with a decrease of 25 million barrels in 1926. This increase in total inventories represented a gain of 12.2 per cent. during the year, and an excess of 6.8 per cent. in supply over demand; see Table 1. Since 1918, stocks of oil in the United States have increased every year, except in 1926. During 1927, the supply of all oil increased 13.7 per cent., whereas the demand for all oil expanded only 4.3 per cent.

Table 1.—*Supply of, Demand for, and Stocks of, All Oil in the United States*, 1925–1927*

Year	Supply, Million Barrels	Change, Per Cent.	Demand, Million Barrels	Change, Per Cent.	Stocks, Million Barrels	Change in Stocks, Million Barrels
1925	870		840		545	
1926	886	+ 1.9	903[b]	+7.3	520	−25[c]
1927[a]	1007	+13.7	943	+4.3	584	+64

* Data from U. S. Bureau of Mines.
[a] December estimated.
[b] Exclusive of 8,000,000-bbl. fire loss in California.
[c] 8,000,000 bbl. of this decline in stocks was caused by a fire loss in California.

Table 2.—*Analysis of Stocks of All Oil*, 1925–1927

Year (Dec. 31)	Light Crude East of California	Light Crude California	Heavy Crude East of California	Heavy Crude California	Natural Gasoline at Plants	Products	Total Stocks
Actual—in Millions of Barrels							
1925	294[b]	44		86	0.3	120	545
1926	225	31	53	87	0.5	123	520
1927[a]	300	21	48	93	0.8	119	582
Change from Previous Year—in Millions of Barrels							
1926	No data	−13[c]	No data	+1	+0.2	+3	−25
1927[a]	+75	−10	−5	+6	+0.3	−4	+62

[a] Nov. 30.
[b] Includes heavy crude.
[c] Partly fire loss.

An analysis of the change in stocks of various types of oil during the first eleven months of 1927, shown in Table 2, indicates that the main sources of oversupply were light crude east of California and heavy crude in California, stocks of products having declined slightly.

The rate of change in stocks of all oil and of crude petroleum east of California is presented graphically in Fig. 1 by months from 1923 to date. This diagram illustrates that the current cycle of overproduction had its beginning during the second half of 1926, became progressively more serious during the early months of 1927, and reached its maximum statistical intensity during the second quarter of 1927.

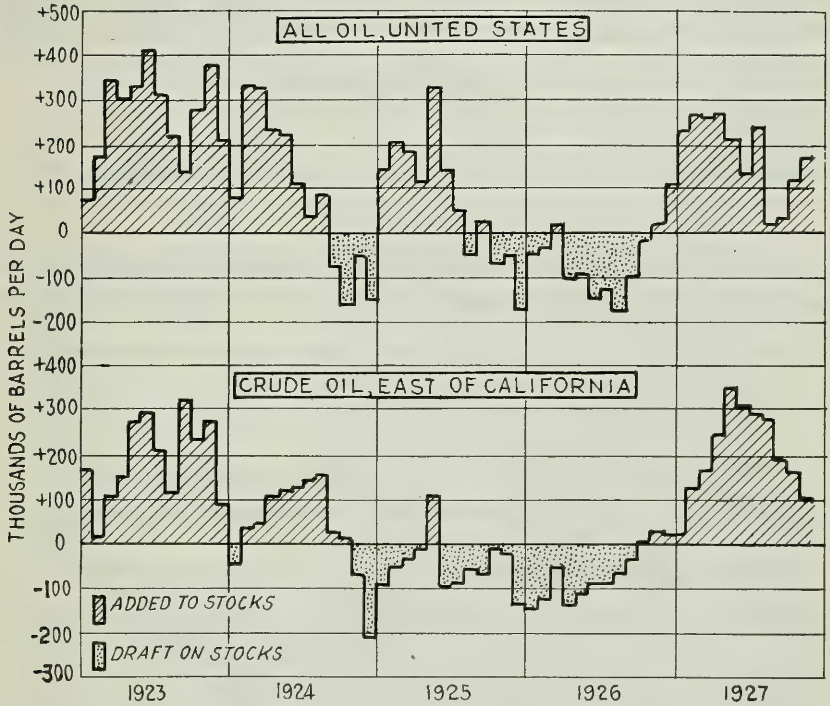


FIG. 1.—RATE OF CHANGE IN THE STOCKS OF (a) ALL OIL IN THE UNITED STATES, AND (b) CRUDE OIL IN TANK FARMS AND PIPE LINES EAST OF CALIFORNIA, BY MONTHS, 1923–1927.

Supply

An analysis of the components making up the supply of all oil for 1927 is given in Table 3 in comparison with the two preceding years, where it is seen that the domestic production of crude petroleum in 1927 increased 16.1 per cent., while imports of crude oil declined 5.5 per cent. and imports of products decreased 33.3 per cent.

The daily rate of crude oil production in the United States (Fig. 2) increased during the first seven months of the year, reaching a record level of nearly 2,600,000 bbl. at the end of July, after which its trend was downward to the close of the year when 2,400,000 bbl. per day was approached.

TABLE 3.—*Analysis of Supply of All Oil*, 1925–1927

Year	Domestic Production Crude	Natural Gas Gasoline	Benzol	Imports Crude	Imports Refined	Total
In Thousands of Barrels Per Day						
1925	2093	72	5	169	45	2384
1926	2112	89	6	165	57	2429
1927[a]	2456	106	7	156	38	2763
In Percentage Change from Previous Year						
1926	+ 1.0	+23.6	+20.0	−2.4	+26.8	+ 1.7
1927[a]	+16.1	+19.3	+16.4	−5.5	−33.3	+13.9

[a] December estimated.

The high level of output attained in 1927 was caused primarily by the extraordinary yield of the Seminole district in Oklahoma and the rise of

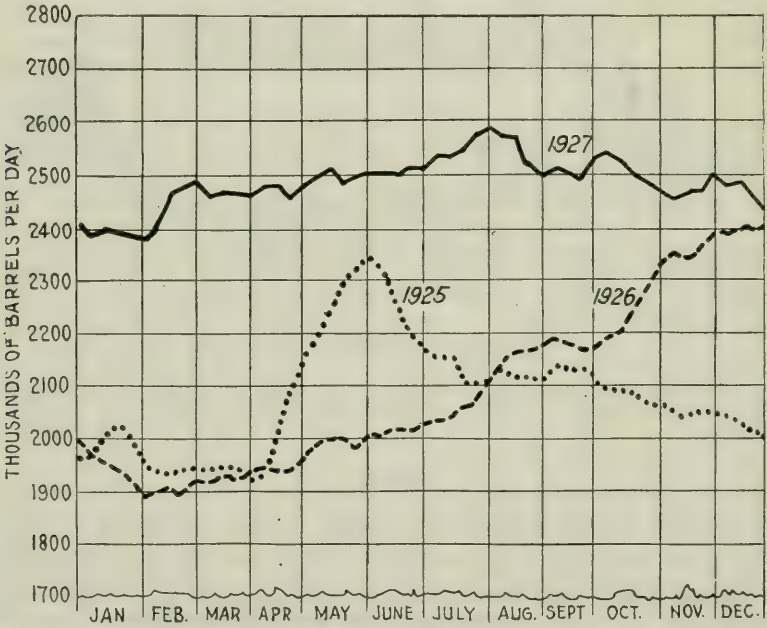


FIG. 2.—DAILY RATE OF GROSS PRODUCTION OF CRUDE OIL IN THE UNITED STATES IN 1927 COMPARED WITH 1926 AND 1925.

production in the Permian salt basin of West Texas. The course and size of these two contributors are illustrated in Fig. 3.

The rate of production in the Seminole district was materially increased by the successful application of the gas-air lift, a relatively new technique

never before applied on a grand scale. The effect of this method of production was to augment substantially, and possibly as much as double, the 1927 yield from this field. The stippled area under the heavy curve in Fig. 3 illustrates the hypothetical contribution made by this technique, and it is an interesting coincidence that the size of this estimated contribution coincides almost exactly with the statistical measure of overproduction in 1927. The Seminole oil is high in gravity and consequently rich in gasoline, and the oversupply of this grade of crude

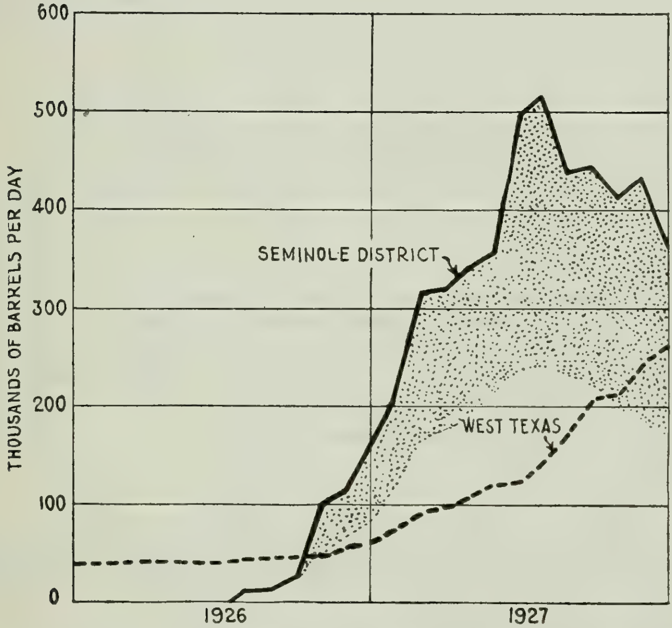


Fig. 3.—Trend of production in the two major oil districts (Seminole and West Texas) exploited in the United States in 1927, showing the rapidity of development of these new sources of supply. The stippled area illustrates the hypothetical contribution made by the gas-air lift.

contributed materially to the decline in the gasoline market. During the year about seven new productive areas were proved in the Seminole district, but their active development was deferred until later by an agreement among the operators.

The Permian salt basin in West Texas underwent very rapid exploration and development in 1927; three major pools were proved and partly developed (McElroy-University, Yates, and Hendricks), and the output of the region was approaching 300,000 bbl. daily by the close of the year (Fig. 3). Because of the isolation of the area and the lack of adequate transportation facilities, however, the output of the district was restrained below its potential capacity and therefore the main contribu-

tion of the region was deferred until 1928. The oil occurs at relatively shallow depths and consequently is fairly low in first cost; but it has a high sulfur content, which increases the cost of refining and cracking. Its gasoline content averages between 20 and 25 per cent., and hence its main contribution, for a time, will be to the fuel oil supply. Because of the premature exploitation of the region, in advance of adequate transportation facilities and a market need for the oil, the operators are faced with very low prices and the predicament of having to enter on a large program of storage. The availability of cheap oil in West Texas has stimulated the construction of several trunk pipe lines, and the physical outlets are undergoing further expansion.

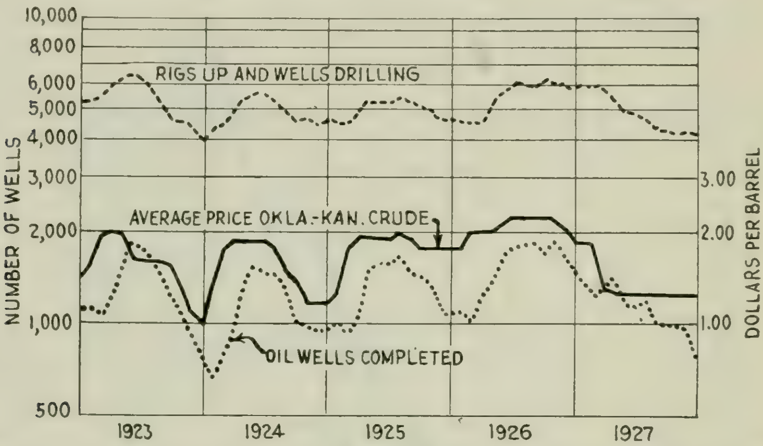


FIG. 4.—TREND OF DRILLING OPERATIONS EAST OF CALIFORNIA BY MONTHS, 1923–1927, SHOWING THE HIGH DEGREE OF CORRELATION WITH PRICE, AND THE DECLINE OF OPERATIONS UNDER THE INFLUENCE OF A LOW MARKET IN 1927.

Other elements entering into the oversupply of crude oil in 1927, though less important than the two described above, include the deep sands in the Spindletop pool in Texas, the Seal Beach and Ventura pools in California, the doubling of the pipe line capacity serving the interior of Colombia, and the rise of production in the Maracaibo Basin of Venezuela, not to mention a sharp increase in the output of Russia and Rumania. An additional factor of undoubted importance, though one that cannot be measured, was the general progress in production engineering leading to a more efficient handling of producing wells and a consequent retardation in their rates of decline.

As a result of the price decline early in 1927, the rate of oil well drilling materially slowed down, as shown in Fig. 4, reaching at the close of the year the lowest level attained in some time. The decline, however, affected wells of inferior prospective caliber and hence the bearing on the total supply was minimized. The importance of flush wells in contribut-

ing to the total supply is illustrated in Fig. 5, which shows the relationship between wells and production. For example, it may be read from Fig. 5 that:

1 per cent. of the wells produce 40	per cent. of the total supply
5 per cent. of the wells produce 65	per cent. of the total supply
10 per cent. of the wells produce 78	per cent. of the total supply
20 per cent. of the wells produce 90	per cent. of the total supply
50 per cent. of the wells produce 96.5	per cent. of the total supply

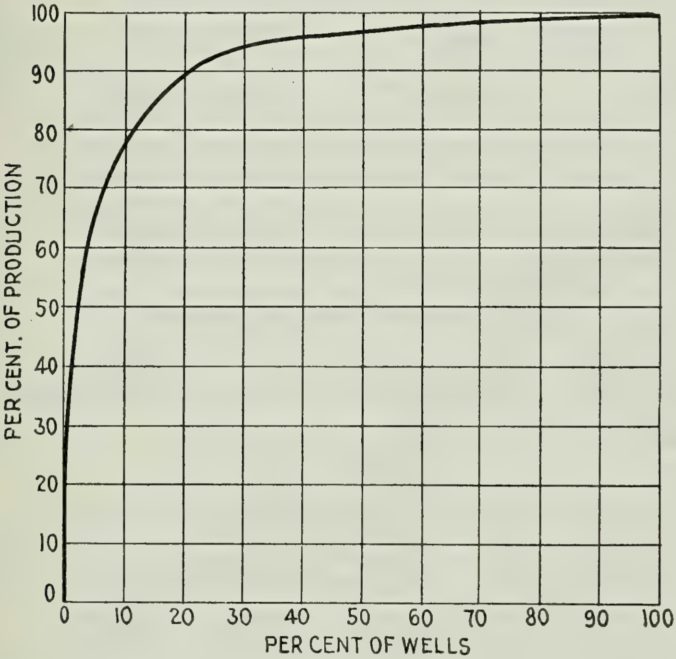


FIG. 5.—CHART SHOWING THE RELATION BETWEEN NUMBER OF OIL WELLS AND VOLUME OF OUTPUT, ILLUSTRATING THAT A VERY LARGE PROPORTION OF CURRENT SUPPLY IS DERIVED FROM A STRIKINGLY SMALL PERCENTAGE OF WELLS. DATA FROM AMERICAN PETROLEUM INSTITUTE AS OF OCTOBER, 1927.

Thus, to put the matter in another way, 96 per cent. of the wells, from the smallest up, are the equivalent in production of 1 per cent. of the wells, from the largest down. As the largest wells are the lowest-cost producers, the difficulty experienced by low prices in retarding production is readily understandable.

Demand

An analysis of the demand for all oil is given in Table 4, where it may be seen that in 1927, as compared with 1926, domestic demand increased 3.8 per cent., exports of crude oil remained unchanged, and exports of products increased 9.3 per cent., an increase of 4.3 per cent. in total

demand. This relatively small increase in demand was one of the adverse factors affecting markets in 1927; accompanying the overproduction of 1923, for example, demand showed a reported increase of 23.7 per cent.!

TABLE 4.—*Analysis of Demand for All Oil*, 1925–1927

Year	Domestic Demand	Exports Crude	Exports Products	Total Demand
In Thousands of Barrels Per Day				
1925	1990	37	274	2301
1926	2114[b]	42	318	2474[b]
1927[a]	2191	42	348	2581
In Percentage Change from Previous Year				
1926	+6.2	+13.4	+16.0	+7.3
1927[a]	+3.8	0	+9.3	+4.3

[a] December estimated.

[b] Exclusive of 8,000,000-bbl. fire loss in California.

For the first eleven months of 1927, in comparison with the corresponding period of 1926, the demand for the principal products showed the following changes:

PRODUCT		PER CENT.
Gasoline	=	+12.3
Kerosene	=	− 6.1
Fuel oil	=	+ 4.1
Lubricants	=	− 1.0
All others	=	− 8.6
Total	=	+ 4.2

The principal components of "all others" as shown in the foregoing tabulations are: crude used as such and losses. The marked decline indicated is probably to be attributed to growing efficiency in the handling and utilization of the raw material, coupled with the encroachment of natural gas as fuel in the oil fields and refineries.[1]

Refinery Operations

The trend of refinery operations in the United States by months from 1918 to date is shown in Fig. 6. The lower of the two curves depicts the actual runs of crude oil to stills, together with the sharp upward trend followed; while the upper curve gives the figures, corrected for seasonal and growth, expressed as percentages of computed normal. It may be

[1] The magnitude of this decline and its concentration in the forepart of the year raises the possibility that it may be due, in part, to errors in the primary statistics.

seen that 1927 was entered with refinery operations at high levels, that is to say, with the refineries overproducing; but as the year progressed the relative trend of operations was downward, though at no time were operations retarded to the point of underproduction, a desideratum for market recovery. It is perhaps worthy of mention that the figures indicate that the refiners of the country during the first part of 1927 supported a

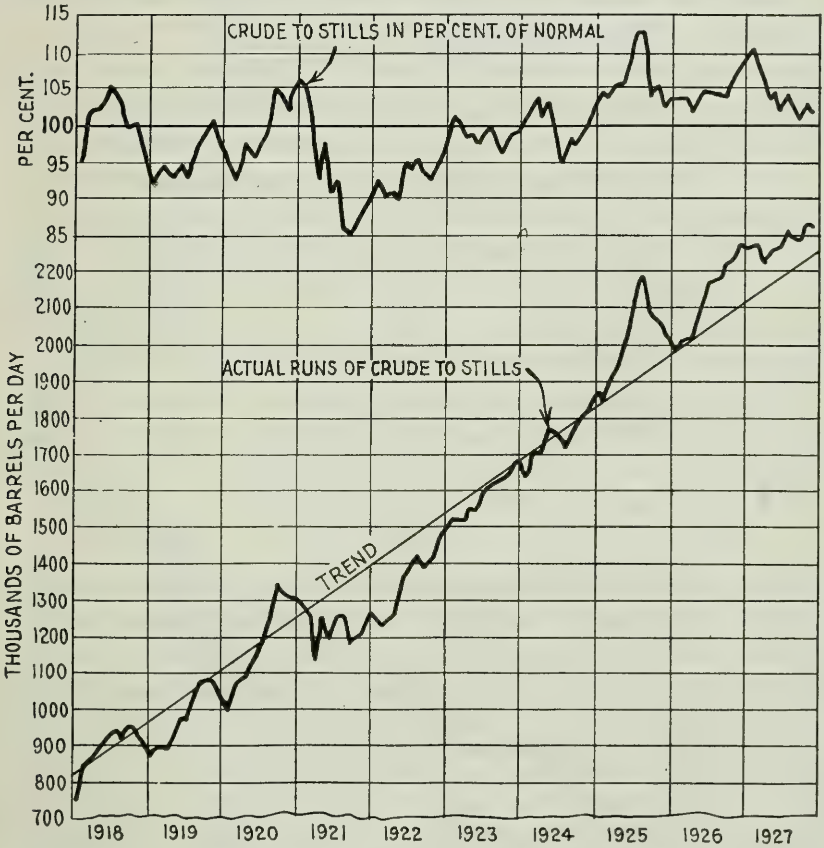


Fig. 6.—Index of refinery operations in the United States by months, 1918–1927.

weakening crude market by inflating their demand for crude oil and therefore contributed to the market debacle that followed.

Gasoline

A remarkable feature of the gasoline situation in 1927 was that, despite the large overproduction of crude oil rich in gasoline, stocks of gasoline were reduced about 7 million bbl., or 17 per cent. This feature is shown graphically in Fig. 7, together with the primary cause

therefor; namely, the retardation in the output of cracked gasoline brought about by the decline in gasoline prices. The stippled area on the lower diagram in Fig. 7 illustrates the hypothetical degree to which low prices were effective in cutting down the supply of cracked gasoline. An

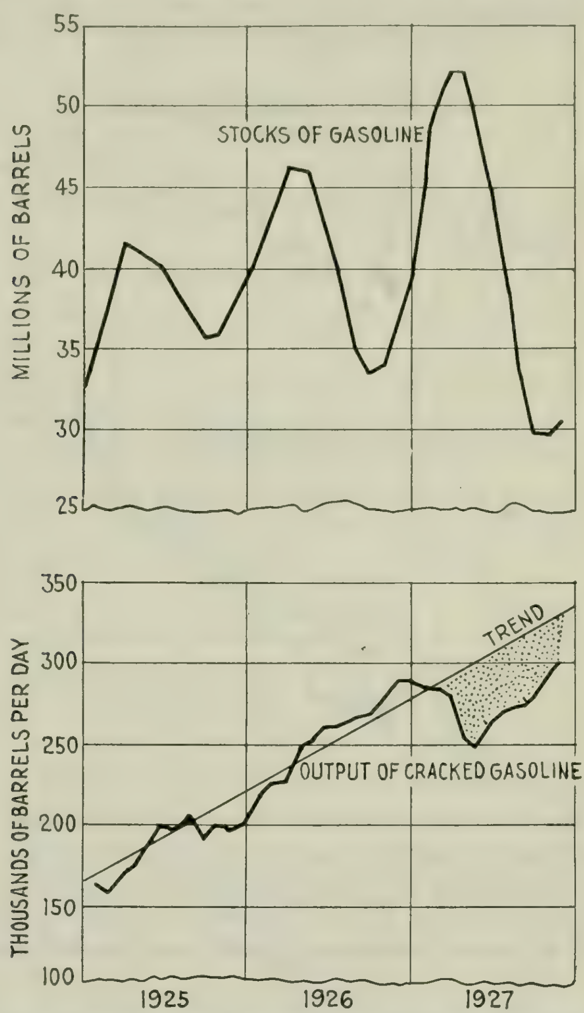


Fig. 7.—Diagram showing, by months, 1925–1927, (a) stocks of gasoline in the United States, and (b) the rate of output of cracked gasoline, illustrating how stocks of gasoline were reduced in 1927 as a result of a curtailment of cracking operations. The stippled area in the lower diagram indicates the hypothetical degree to which cracking was curtailed and retarded under the influence of low prices.

interesting outcome of this situation was that, whereas for nine years previously there had existed a high degree of correlation between price and gasoline stocks had existed (with the growth and seasonal elements

eliminated), in 1927 the relative level of stocks was gradually reduced without improvement in price. The presence of unused cracking capacity apparently acted in lieu of stocks in its economic effect.

Comparative data on the gasoline situation in 1927 and the two previous years are given in Table 5. It is there seen that in 1927, the supply of gasoline increased 10.0 per cent., while the demand for gasoline enlarged 12.2 per cent., thus causing a reduction in stocks.

TABLE 5.—*Gasoline Data*, 1925–1927

Year	Production Cracked Gasoline	Production Straight-run Gasoline	Natural Gasoline	Imports	Total Supply	Domestic Demand	Total Demand	Stocks End of Year
				In Millions of Barrels				
1925	69	173	17	4	263	224	255	39
1926	94	182	24	6	306	262	305	39
1927[a]	102	198	32	5	337	298	343	33
				In Percentage Change from Previous Year				
1926	+36.2	+5.1	+41.0	+50.0	+16.3	+17.0	+19.6	0
1927[a]	+ 8.6	+8.9	+33.3	−16.7	+10.0	+13.7	+12.2	−15.4

[a] December estimated.

Fuel Oil

The fuel oil situation was unfavorably affected in 1927 by the oversupply of crude oil, the retardation suffered by cracking, and the slow rate of growth in demand brought about by the high prices prevailing in 1925 and 1926. Later on in the year, the growing output of low-cost crudes in West Texas and Venezuela had a further depressing effect, and fuel oil prices ended the year at the lowest levels for that period. The fuel oil situation has been especially handicapped by the manner in which the product has been merchandised, in respect to the lack of assurance of a stable source of supply extended to prospective consumers and a general neglect of means for extending its higher-use markets. Low prices may be expected to bring growing attention to these matters.

Prices

The statistical developments of the petroleum industry naturally resulted in a drastic decline in prices, the degree and severity of which is shown in Table 6 and Fig. 8. The major declines took place toward the close of the first quarter of the year, but prices weakened further and closed the year at low levels, representing the longest price depression experienced by the industry since 1914–1915.

TABLE 6.—*Trend of Relative Prices of Crude Petroleum and Its Principal Derivatives in the United States,* 1913 *to* 1927, *Inclusive, and by Months,* 1927

Prices in 1913 = 100

By Years	Crude Petroleum at Wells	Gasoline, Tank Wagon	Kerosene, Tank Wagon	Fuel Oil at Refinery	Lubricating Oil Jobbing Quotations
1913	100	100	100	100	100
1914	82	83	97	85	101
1915	66	75	90	68	97
1916	117	121	101	98	119
1917	155	132	108	147	126
1918	195	139	130	189	200
1919	197	142	162	149	209
1920	302	170	217	262	318
1921	163	143	164	122	179
1922	156	140	158	117	132
1923	150	112	163	113	125
1924	161	102	162	127	149
1925	172	106	156	137	170
1926	178	112	187	138	170
1927	136	96	164	108	165
MONTHS 1927					
Jan	165	109	175	139	157
Feb	164	108	172	139	163
March	137	102	169	131	163
April	133	96	168	117	165
May	131	96	162	103	166
June	131	93	161	98	167
July	131	94	161	98	167
Aug	128	92	161	94	168
Sept	128	91	161	94	169
Oct	128	91	161	97	167
Nov	128	91	161	91	161
Dec	130	91	161	88	158

The change in the average price level in 1927 from 1926 may be briefly summarized as follows for the principal commodities:

PRODUCTS	PER CENT.
Crude oil	= −21
Gasoline	= −14
Kerosene	= −12
Fuel oil	= −22
Lubricants	= − 3

These changes are approximations merely as they represent posted and spot prices; contract prices for gasoline and fuel oil particularly would doubtless show larger downward revisions.

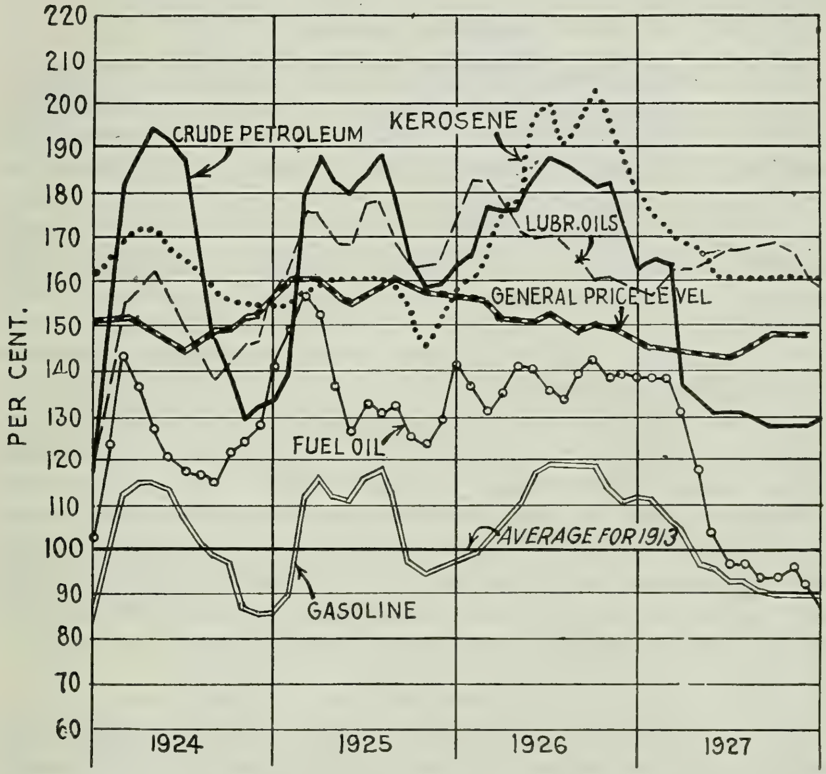


FIG. 8.—TREND OF THE RELATIVE PRICES OF CRUDE PETROLEUM AND ITS PRINCIPAL DERIVATIVES IN THE UNITED STATES BY MONTHS, 1924–1927, IN PERCENTAGES OF THE AVERAGE PRICES IN 1913 AND IN COMPARISON WITH THE GENERAL PRICE LEVEL. (PRICES IN 1913 = 100.)

Financial

The drastic decline in prices was naturally accompanied by a serious impairment of earning power on the part of oil companies. While the results for the full year are not yet available, the quarterly reports of 23 oil companies reveal a net income of $56,000,000 for the first nine months of 1927 against $132,000,000 for the corresponding period of 1926, a decline of 58 per cent. This reduction in earning power was also reflected in a liquidation of oil securities, which declined on the average about 17 per cent. between the end of February and the Middle of July, when the low point for the year was reached.

It may be noted that the conditions of easy money prevalent in this country in 1927 not only prevented a more serious decline in oil securities

but enabled oil companies to finance themselves for current operations and even in many instances for expansion, approximately a half billion dollars of new capital having gone into the oil industry during the year for these purposes.

Economic Control

As the year progressed, the industry directed growing attention to means for gaining greater economic control over supply. In the case of the Seminole field, the operators entered into a cooperative agreement for prorating production at the peak and for the restraint of drilling around new discovery wells; as a result, a number of pools in that district have been deferred for development later. In the Yates pool in West Texas, proration measures were instigated to obviate the storage of large volumes of oil, as would have been necessary if production had gone forward unrestricted in the face of inadequate transportation facilities.

The Federal Oil Conservation Board devoted further attention to the study of the oil problem and late in the year appointed a committee of nine, representing the Government, the oil industry, and the American Bar Association, to study the economic and legal aspects of overproduction and to recommend legislation bearing thereon. Also, at the annual convention of the American Petroleum Institute in December, the oil industry recorded itself as favoring a policy of state legislation to effect the conservation of natural gas as a means of regulating crude oil production. So far, the efforts looking toward the control of supply have been directed more along legalistic channels than in economic directions.

Conclusions

The seriousness of overproduction during 1927 and the widespread realization that the productive capacity of the industry has been so overstimulated that any early fundamental betterment in the situation must come from the development of economic restraint, rather than as a result of a natural decline in supply or a normal growth in demand, have brought to the fore a new point of view in the industry—one that will doubtless struggle for greater recognition and clearer definition during the current year. The necessity for greater economic control in the production of oil is becoming rather widely recognized, but the means for achieving this result are by no means clearly envisaged and as to them the greatest diversity of opinion still prevails. The problem is extremely intricate, and time will doubtless be required for new economic forces to get established and become effective.

DISCUSSION

L. W. Mayer,* New York, N. Y. (written discussion).—We hear much about oil being what you unhappily call a fugitive material and all the ills of the industry seem

* Mining Engineer, Rogers, Mayer & Ball.

to be laid at the door of this condition. It seems to be felt that because oil is mobile the problems in the industry are entirely different from those of the metal industry. I do not agree fully with this view, and really think that the industry uses it as an excuse for not meeting the problems in connection with which not nearly enough effort appears to have been made. It must be admitted, of course, that it is easier to treat with a material one can see in place than with one, as in the case of oil, which, generally speaking, is not seen until it is about to be consumed—if then. The fact that oil is mobile does not, to my mind, explain the necessity of overproduction. It may in a particular field, but what about the intense wildcatting in totally prospective areas during the past years and even the present time? Where has it gotten the oil industry? Would we not be better off today if wildcatting had been restricted say five years ago? It is difficult to understand where this persistent policy to find more and more oil has helped the industry, but not so hard to see that it *is* getting it into a position similar to the coal business, and that is a rather doleful prospect.

The copper industry was heading the same way as a result not only of new deposits discovered, but because of great improvements in mining methods and in the metallurgical art. The lowering of mining costs and the improvement in recoveries at going properties account more for the increased production of copper in recent years than the discovery of new deposits. Much lower grades than formerly can now be treated at the old costs. This is tantamount to greatly increasing the world's copper ore reserves. In your industry a tremendous opportunity to recover more oil from the sands and to decrease costs by more scientific methods seem to be possible, so that the situation between oil and certain of the metals is analogous. It has always been a wonder to many in the mining industry that such a thing as a shortage of oil could be contemplated, because we are mindful that you recover what really amounts to only a moderate percentage of the oil in the sands, and that the improvement in methods of oil finding has only begun. The fact that you could so easily locate fields like the Yates, where we understand you have 15,000 acres believed to contain 45,000 bbl. to the acre recoverable by present old methods, and also the fact that in a few years you have proved huge reserves at Maracaibo and already deliver here from that jungle, at less price than Texas oil, is certainly suggestive. Still the oil industry continues to compete and pay for more and more oil lands, as if a shortage were imminent. We have heard of moratoria whereby people are relieved for a time from making good their debts, and such a thing as a moratorium in the buying and wildcatting on oil lands might not be amiss, because if the land is let alone, oil is not so mobile that it will get away if no development is carried on.

The copper people took years to get together and really cooperate, one with the other, probably in part for the same reasons as your industry now seems not to fully cooperate. By force of circumstances such as those to which you seem destined, the copper interests are now carrying on with restricted production, without interference. If it is possible with them, in so far as the legal phase is concerned, then the oil industry should be able to do this also. I would not say that the copper industry is in a condition of fulsome prosperity, but the spirit of cooperation is now splendid. A fair price for the metal exists, due to a reasonable balance between production and consumption, and this despite excess potential supply and excess capacity to produce. It has been made possible in part through corporate consolidations, and that is what you must set out to further; we see little concerted effort on your part to popularize oil, to increase your consumption or find new uses for it. Our Copper Export Association, the Copper Producers Association and particularly the Copper and Brass Research Association, all relatively recent creations, have served as a great impetus to consumption.

I should not want to appear hypercritical, but there really seems to be no industry where the room is greater for intelligent cooperation than with oil, to say nothing about

the possibility for improvement in production engineering. It really appears to the mining industry as though your field were wide open. That such a situation exists might be accounted for by a state of mind; too great ease in securing capital. This seems to be the fundamental cause of overproduction. You have been overprosperous in the years past. Your profits have come too easily and it is feared that unless the situation is quickly met, you will, by mere force of circumstances—whether you like it or not—have to see accumulated balance sheet surpluses largely fade. Improved engineering will, of course, mean the bringing down of costs. The bringing down of costs will lower the price and increase consumption. It is felt, with the much desired consolidations previously referred to and the consequent adjustment, that the present price of oil will then seem quite satisfactory. It also seems to be greatly desired that the industry temper what has seemed to be a fetish rather more than an absolute necessity in all cases, to acquire more and more land, when the supply of oil is excessive. In that way the price of oil lands will be lowered, thereby also reducing overhead carrying charges, which, in the case of lands where there is no intention of developing for years to come, certainly must be a heavy corporate drain.

If you are interested to hear the impression that the outsider gets of the oil industry, it is that the business is not sufficiently intimate with the word "economy" and that it will absolutely have to become so; that its great opportunity is improvement in production engineering; that there is a strange lack of public knowledge as to production costs in the various fields. The public has no idea what it costs to produce oil or its derivatives, but it has an idea that the profits are large, which of course is not the case—with most companies, at least. This suggests the epigram, "It ain't so much people's ignorance that does the harm as their knowing so darned much that ain't so." The outsider feels the policy of acquiring additional lands is overdone by many interests and, on balance, to the detriment of the shareholders, and this is said without being unmindful of the necessity, up to a certain point, to replace extracted oil. It is felt, though, that the shareholders for some years past have not received a fair portion of the earnings, due to excessive diversion of profits into land investments at prices not consistent with the time when these lands—some remotely located—are likely to be made revenue-bearing.

H. S. Reavis, New York, N. Y.—The oil industry is sobering up after an era of excesses and extravagances which lasted from 1916 through 1926. Mr. Pogue has described certain phases of it accurately but quite conservatively. I would amplify what he has said by stating that speculative elements dominated the industry during a considerable part of the 1916–1926 period, and were in control of the highly important department of price-making. They could do this so long as there was life in the bogey of "insufficient supply"—the delusion that we were just a few steps ahead of a crude-oil famine. But we now have more oil than we know what to do with, and it looks as if we will have to face this condition for some years to come. As a result, boom methods and bonanza ideas must give way to voluntary or involuntary control of drilling and production; extravagance must be replaced by drastic economies. We must realize that primarily our industry is an unexciting manufacturing and merchandising business, not a thrillingly spectacular and speculative enterprise. It may be an unwelcome thought but we must face the necessity of trying to make a penny or two a gallon on our manufactured products instead of a dollar or two a barrel on our crude oil. Mr. Rockefeller and his associates in the old Standard Oil group were manufacturers and merchants—they were entirely willing to have others do the speculating in crude-oil production. We have had our crude-oil boom and now, if we want to be sure of a living, we must take our cue from the old Standard Oil group and concentrate our energies on getting that penny or two a gallon profit on our manufactured products.

F. J. Fohs,* New York, N. Y. (written discussion).—Mr. Pogue's figures showing a loss of 58 per cent. in oil company income for the first nine months of 1927, with increased sales and increased efficiency, speak more loudly than volumes as to the present status of the industry, as does the decline of 17 per cent. in the value of securities. As Mr. Pogue indicates, many causes have contributed, but—if I may be so radical as to suggest it—would not the industry be better off if the oil company executives had refused to appropriate additional funds and its bankers had refused to finance (1) new oil pipe lines to West Texas, (2) building steel storage for Seminole and West Texas, (3) doubling pipe line facilities in Colombia, and (4) building lake tankers for Maracaibo?

The failure of the large companies controlling Venezuela and West Texas to shut in one or both, in the face of what losses their exploitation meant to themselves and the industry, is incomprehensible, except on the business theory that each subsidiary must show results, even if it result in failure to all. Here is an instance where the companies in control have clearly damaged themselves equally with the small operators.

Our ideas of storing oil above ground must be just as effectively revised as those of the retail merchant of prewar years, maintaining large merchandise stocks where now he maintains a minimum to cover requirements. A half year's supply is not warranted with the large potential reserves of California, Texas, Oklahoma, Venezuela, Persia and Iraq.

The announcements today in the *National Petroleum News* that there is a fair chance that 50,000 bbl. of heavy and 20,000 bbl. of light oil may be shut in California by March 1, is highly significant of the new spirit which is coming into the oil situation.

I think the capping of isolated wells, as has been done through the efforts of economic circumstances during the last half of 1927, answers Mr. DeGolyer's statement that the old theory of opening a new well in a field must necessarily have the same effect as the "pulling of a trigger of a gun." I do agree with him that the geologists have been somewhat to blame and in my suggestion that the executives and bankers view the picture in the large to a greater extent than they are now doing, I do not intend to eliminate other factors which also have played a part. In fact my conclusions, as then stated, hold—that this is not a "one point problem but a five point problem" in which all factors must be considered and each put into its proper place—and by this I mean that those who are responsible for the progress of the industry must no longer be self-centered on one particular phase of the industry but must take into consideration all phases of the industry, including production, refining, transportation and marketing.

J. M. Lovejoy,† Tulsa, Okla.—Regarding the spirit of cooperation which has developed during 1927, the shutdown movement at Seminole at first did not amount to much because we were trying to prorate or restrict drilling in pools that were already half developed, but toward the middle of 1927 and the latter part of the year, when new pools were discovered in Seminole, it was almost beyond belief that the producers were willing to actually shut in a big new discovery well, shut it right off and leave it there, and it stands that way today.

The latest development from the shutdown committees on Seminole is that they have permitted a restricted development of the south and the east extensions to the Little River field. It was decided today that 10 new wells would be drilled to test this area and will be shut in when completed. The other high spots in the Seminole district, proved spots, proven for production, are still shut in until April 1, and the period of restricted drilling may last even longer than that.

---

* Vice President, Humphreys Corpn.

† Vice-president, Amerada Petroleum Corpn.

E. L. DeGolyer,* New York, N. Y.—Our willingness to buy oil stocks might be due to the fact that we have no national lottery. There are two problems in oil. One is the problem of finding it, and the other is the problem of production. I do not know whether anybody knows what it costs to find oil.

I should like to be able to agree with Mr. Pogue that the entire question of production followed so closely the price curves or the economic demand as he indicates.

Mr. Reavis has had experience in Spindletop oil, and 5-c. oil did not stop the development of the Spindletop pool. It went right ahead. Price will not stop the development of one of these big pools, once it is discovered.

Mr. Lovejoy will remember that on a recent trip to Tulsa, we checked up and found a number of independent producing companies with about $1000 a barrel in bond issues out against their current production. I do not think anybody would give $1000 a barrel for the production today. That, however, is the bankers' business; they have to be satisfied about their securities. If oil that is not worth $1000 a barrel is ample security for $1000 in bonds, that is their business and not ours.

We have to learn to keep the oil in the ground. I have thought about this a good deal, and I think the difficulty lies in the fact that we all think we are a little bit smarter than anybody else. It gets right down to the matter of competitive production. I do not know who the original jurist was who decided that oil partook of the nature of the wild beast and it was only property after it had been reduced to possession, but that is the fundamental basis of the whole trouble.

As to competitive production, what is your excuse? The excuse usually given is that you are trying to protect your lease. Who are you trying to protect it against? You are trying to protect it against your neighbor. As you go around and canvass him, he is trying to protect himself against you. The fact of the matter is that either you or he is trying to get, by aggressive operation, more than your share of oil out of the lease, and the other, willy-nilly, is forced into following your operation. It probably occurs to him that he may be able to beat you at your own game, and then the race is on.

As a matter of fact, I suspect that over a long period of operation and in well-conducted companies, the ability to extract oil from a lease is about the same. Company *A* might get off to a running start in one particular field and get a little bit more than its share. It might even do it in the next field and the third one after it, but over a long period of years, I suspect company *B* would be just about as well managed and handled and that it would get just about its share of the oil, too. I think that this shows the fallacy which is the chief source of our difficulties.

I think a great deal of the criticism Mr. Mayer suggested with regard to the oil industry is well founded. In trying to take issue with him on certain points, I will not fall back on the time-honored excuse that oil is a fugitive mineral. The fact is that it is rather difficult to compare oil with the mining industries fairly unless you take into account the fact that we have no comparable tangible reserves. That is the reason that money is spent for land. The normal course of the development of an oil field involves the taking of 50 to 60 per cent. of the total content of the field out within the course of a year or 18 months after the discovery. The extraction of the remaining 40 to 50 per cent. is a rather slow and tedious process which extends over the remaining years of the life of the field and cannot be greatly accelerated. In order to maintain production at all, we are constantly forced to search for additional oil fields and our success in finding oil, considered in terms of barrels, is not necessarily proportional to the amount of effort put into the search.

As an example, I might cite the Humble's efforts in East Texas and all of the effort that has arisen out of its initial discovery there, which has not resulted in the

* President, Amerada Petroleum Corpn.

production of a single barrel of oil as compared with the efforts of the Transcontinental which opened up the Big Lake pool, and in so doing opened up all of West Texas and brought down on us a tremendous flood of oil.

One of the remaining points I want to touch on is the fact, the paradox, if you will, that in times of overproduction the only man who can make money is the man who has great flush production. In other words the man who is causing the greatest amount of harm and damage is the only one who can keep his balance sheet in the black. I suspect at the present time that production could easily be divided between flush production and more or less semisettled production, and the only production at all that is making any money is the flush production. In other words, today if a few of us raise enough money to drill a wildcat well and go out and get 2000 or 3000 acres and get a well, we can make money no matter what the price of oil is. The men who are trying to conduct an oil operation as a continuing business may not be so fortunate, they may have to lose money this year or next year, particularly if we and others of our ilk should be successful in wildcatting, but there are these very fundamental differences.

Our reserves, if you want to call them that, are a hand-to-mouth affair. Consider Fig. 5, showing, let us say, 50 per cent. of the production from 3 per cent. of the wells. From those 3 per cent. of the wells, the production is flush, and if it is flush, you might almost say it is probably from fields that were undiscovered a year, 18 months or, at the most, two years ago.

So the great problem of our reserves is the problem of constantly finding more oil. If oil were worth only 10 c. a barrel, we would all be out trying to find oil, because after all, it does take time. We would be out trying to find oil against the time 1 year, or 2 years or 3 years from now when it might be worth more, and if we did not do so, we probably would suffer from underproduction at that time.

I would like to go back to the geologist, being one myself and this organization being originally a group of geologists. We might just as well look the fact right square in the face when we are passing the blame around. We have had about as much to do with it as anybody because I suspect everybody from the first geologist on down, until the beginning of the present period of overproduction at any rate, has been talking about a shortage of oil. The only trouble is that the leaders of the industry believed the geologist for a while; I do not know that they do now.

I suppose the first geologist who ever saw the first oil well, in view of the fact that his experience did not compass anything of that sort, must have shaken his head and said, "This thing certainly can't go on." At any rate, since the very beginning, geologists have predicted a shortage.

J. P. Leslie, an honorary member of this Institute, and a scientist, who was eminent enough in his time to be President of the American Association for the Advancement of Science, State Geologist of Pennsylvania, at that time a great oil-producing state, during the year in which I was born, addressed a meeting of this Institute in Pittsburgh and warned the members that the production of oil at any such rate as was going on at that time could not continue. He said, "Our children will with difficulty drain the dregs of this once magnificent heritage if things go on like this."

I do not think we need pass the blame on to the bankers. One of our troubles is that we are trying to pass the blame on to somebody else. The oil industry has to learn to develop some restraint and keep reserves in the ground. It works both ways. It is not a question of supply, but it is a question of stability of the industry itself. This business of a single producing company being away up in the clouds in March and away down in the depths in October because its production has gone from 60,000 down to 20,000 bbl. is not right—if we could learn to hold oil in reserve, if we could learn to work out more of these cooperative agreements and hold our oil and produce

it when needed, the entire problem of the industry would be solved, and it will have to be solved by the industry itself. That is the answer.

L. W. Mayer, New York, N. Y. (written discussion).—It is strongly felt the trying experiences of certain of the metal industries in recent years should be of benefit to the oil industry. May I therefore lead up further to comparison of the two businesses.

It has always been a matter of curiosity to many of us in mining to observe the huge valuations which the market places on oil properties, and I have heard it frequently remarked among mining men that they have rarely observed instances of oil companies selling on the market at figures reconciled by what their intrinsic value appears to them to be. It seems not unusual to note oil companies selling on the market for hundreds of millions of dollars, which is the exception in the case of mines. Oil companies selling for $50,000,000 on the market appear to be frequent, even though the earnings might show only 6 per cent. profit, to say nothing of dividends which, for some reason, the independent companies are very sparing with, if they indulge at all. It would seem that if the term "hand to mouth" as expressed by Mr. DeGolyer can be applied to the oil industry, it is rather in the matter of return to share holders for some years past, and the comparison between earnings and market price of the companies' capitalizations, rather than in the matter of consumption of known oil resources of individual companies.

I have often put the question to oil men as to market valuations, and the answer invariably has been that one is not justified in measuring the value of these properties by the dividends they return, because they possess enormous reserves of oil, profits from which will sooner or later inure to the shareholder. Still such companies are among those which are in the race for more oil lands and always prepared to enter upon a wildcatting campaign; so that it is difficult to reconcile this condition with the information that the oil business is a hand-to-mouth proposition or to the often-heard expression that, unless additional lands are continually acquired, they will go out of business. Of course, it is not difficult to appreciate that in the case of small companies, which, by the nature of things, can hold only a small acreage at one time, the latter contingency is true, but to my mind there is really no room for small oil companies, generally speaking, as evidenced by the fact that it is exceptional for a small oil company to be successful. This prompted my view that consolidation, with a view to lowering costs, is one of the important activities which the industry must further.

Mr. DeGolyer has, as usual, gotten to the root of the discussion in stating that one of the great needs of the oil industry is that it must learn to conserve reserves. It is my belief that you are going to find this easier than anticipated. It is a pity that dire necessity should bring it about, though perhaps I am not sufficiently tolerant in allowing for the frailties of human nature.

You may be interested to know that there are several important mining companies which now find they have added excessive capacity to their plants. These additions, however, are now restricted as to output, and a case may be cited where they have left idle for more than a year now an enormous new plant unit, fully capable of practically doubling this company's output and with more than sufficient ore reserves and mine facilities to provide tonnage even beyond that. However, it is realized consumption is incapable of absorbing the metal output which would ensue if some of the larger mines now released additional tonnage, which they are in physical shape to do, but not without contributing to the disturbance which would follow, to the detriment of the industry as a whole.

I find it impossible to subscribe to the view that the oil industry is not analogous to other mineral industries. I can see no fundamental difference between a mining company having 10 to 20 years of reserves and an oil company which has such a life

in prospect, provided the company's acreage is not scattered in small blocks and thus subject to drainage. It is to benefit the latter cases that changes in governmental policy are sure to come through sheer necessity. There are, however, frequent instances of companies owning large new acreages not subject to drainage where production does not come from line wells.

Ordinarily, if a mine has, say, a 20-year life, to all intents and purposes, the question of amortization is not very serious, so that such a company does not exert unusual effort to block out ore beyond that. After 10 years or so have passed, however, they then begin to think of acquiring additional properties in order to continue the enterprise, but experience has shown that in such a period improvements in mining methods and metallurgical procedure ensue and ores which, at the beginning of the period, were uncommercial, may be considered commercial, by the end of the period; so that additional ore automatically comes into reserve. Your preparation to recognize the need for production engineering, as pointed out by Mr. Umpleby, will bring about similar conditions. The watchwords of the oil industry should be "Economy" and "Restraint" which, if exercised, will bring about more stabilized conditions, now non-existent largely because the entire structure of the industry, the price of lands, the rate of exploration, the duplication of facilities provided for consumption and the valuations, are immoderate.

A. Knapp,* Philadelphia, Pa.—The consumption of petroleum seems to be increasing lately at a decreasing rate. It takes some time to find these changes because, particularly in gasoline consumption, they are very seasonal. Referring to Fig. 7, gasoline stocks increased for a long time and then flattened out. It took about 18 months of flattening before you could find it mathematically, because of the seasonal trend which is in it. If gasoline consumption is analyzed mathematically for 12 months, it will show a decline in the rate at which gasoline consumption has been increasing. We find minor changes in rate of increase of consumption of other petroleum products. I am giving you a pessimistic picture as a warning that increasing consumption is not the way out. I think Mr. DeGolyer's thoughts are excellent that the industry will have to turn inside of the circle to find the cure.

M. W. Ball,† Denver, Col.—It has been said that the oil industry will never be comparable to other industries until it reaches the stage where it maintains reserves of its raw material in the ground. There is some indication that it is beginning to approach that stage. West Texas is being held back on account of lack of transportation facilities, and there seems to be general agreement that this is a fine thing for the industry; the Maracaibo Basin is being held back by the lack of tanker transportation, and it might be well if it were still further constricted; the seminole situation is being held in hand by agreement not to open up and develop the new pools in that district; in Salt Creek the great amount of oil in the Lakota sand is being produced at perhaps 15 per cent. of capacity, and the great amount in the Sundance sand is being left untouched.

Just to the extent that these things are being done we are creating reserves, almost for the first time in the history of the industry. They are not ideal reserves because, except for Salt Creek, they are not being ideally maintained. Perhaps the Maracaibo Basin comes closest to it. In West Texas every operator is doing his best to get his oil out, subject to such arrangements as they have made at Yates; moreover, taken by and large, each operator is doing his best to get out a little bit more oil than the other fellow can get out. Nevertheless, conditions are such that the operators are unable to get all the oil out, and possibly, just possibly, some of that oil will be held

* Petroleum Engineer, United Gas Improvement Co.

† President, Argo Oil Co.

back even when it might by some means or other be gotten out at a low price. Possibly the few companies that are in control of the Maracaibo Basin production will not build all the tankers they can build, but will confine their output to a moderate amount such as they are handling now, or will be able to handle in just a few months; and, possibly the Seminole operators will continue to keep the new pools in Seminole shut in for a while. If so, if these possibilities become actualities, we will be beginning to get a toe-hold on having some reserves in the oil industry.

When we begin to get reserves, will not our whole economic structure be changed? When we have some reserves we may not have these violent fluctuations of prices. If we have in West Texas and in Maracaibo Basin and in Seminole and in San Joaquin Valley and in Salt Creek a few hundred million barrels of oil in the form of reserves underground, we may not be able to look forward to an increase in price every time crude stocks are drawn on; the reserves will be there, furnishing a stabilizing factor to keep prices on a more uniform plane.

Perhaps we are entering on an era in which we will not get prices away up this month and away down six months from now and away up six months thereafter. If prices are thus stabilized by the building up of reserves—and I realize just as fully as you do that I am indulging in the wildest sort of prophetic speculation—by the creation and maintenance of reserves in the ground, is it not likely, and might we not just as well look ourselves in the eye and say so, that the prices will be stabilized, not at peak prices by any means, but at relatively low levels? Probably they will not stay as low as they are now—it is to be hoped —but they will be below the top levels of the past few years.

It follows that a man who is going to produce oil at a profit in years to come, after we get on a reserve basis, will have to produce his oil at a low cost. That is possible, of course, for the man who has flush production; he can produce it for almost nothing. But after all most of us are not producing flush production; once in a while some one of us is lucky enough to have some flush production and to make some money out of it, but most of us most of the time are producing settled production. Is not the problem ahead of most of us to develop the ability to produce settled production at smaller costs? This probably will mean large operating units in which greater economies can be effected, improved engineering practices, a buttoning up, a tightening up, a drawing in of our ranks, an intensive study of every possible economy in getting the barrel of oil out of the ground at the lowest possible cost.

J. M. Lovejoy.—I do not see how we can get away from a long period of low prices, and we must adjust our operations to a lower plane of costs, get more oil out of a given pool at less cost, and that will be partly the job of the production engineer.

W. A. Sinsheimer,* New York, N. Y.—A point Mr. Pogue has suggested that I would like to emphasize is the possibility of technology being applied to the enlargement of markets for petroleum products. The effort of the technical man on oil production problems has, we know, been a big factor in building up the supply of this product; likewise, he would undoubtedly be of marked assistance in establishing new uses and accelerating the demand. It is believed, too, that more serious attention must be given to the economic effect of the increased production of oil in foreign countries. Today Venezuela is exerting a large influence, and it is not impossible to conceive that Russian and Persian oil will seriously affect our export markets.

It is believed that more consideration must be given potential and shutin production, the latter being estimated today at 300,000 bbl. daily. In a way this oil is really a current supply and a true economic picture is not portrayed without measuring it as production.

---

* Land and Oil Production Dept., H. L. Doherty & Co.

It is believed that Table 6, showing the change in average price levels in 1927 from 1926 is a bit misleading, in that he has used the tank wagon prices for gasoline and kerosene and wholesale prices for other products. Were he to use the average refinery prices, it would be noticed that the gasoline price showed a decline of 25 per cent. and kerosene 30 per cent., and that the decline of all the major products was greater than the drop in the price of crude oil.

Does it not seem possible that the low price which has existed for the past 12 months is having its effect? A year ago there were 44 per cent. more oil wells being drilled than today, with a corresponding change in well completions. Can 20 per cent. of the wells continue to produce 90 per cent. of the total supply?

Chapter XV. Petroleum Products

Economic Aspects of the Gasoline Situation

By Barnabas Bryan, Jr.,* New York, N. Y.

(New York Meeting, February, 1928)

The tank car price of gasoline today is controlled by oil in the ground, rather than by stocks of gasoline or methods of refining. Previous to the commercial cracking of fuel oil, there was a normal and continuous relation between gasoline stocks, consumption and prices. From the beginning of the new cracking era in 1923 to the summer of 1926 there was a changing relationship, growing toward a correlation between the potential gasoline in storage and the price of gasoline. Since the development of large reserves of shutin production in Wyoming, California, Seminole, West Texas and Venezuela, the relationship between stocks of gasoline and gasoline prices has disappeared. The extreme depression of the Group 3 price can only be accounted for by oil which is not being produced but which we fear may be produced at any time.

In Fig. 1, the curve of gasoline stocks is simply stocks of finished gasoline. The curve of potential gasoline is made by taking 40 per cent. of all stocks except gasoline, kerosene and lubricants, adding to that stocks of finished gasoline and dividing the sum by total gasoline consumption to get the months' supply of gasoline at the current rate of consumption. The price curve is the lower figure given by the *National Petroleum News* for the first quoted date of each month, with the price scale reversed.

Stocks of potential gasoline have decreased from 17 months' supply at the peak of 1924 to a low of 7 months' supply during the past summer, yet the low immediately precedes the lowest price for gasoline since it was a waste product. The tendency of the price curve to parallel the curve of potential supply is quite pronounced until the summer of 1926, since which time they have abruptly separated. The curve of gasoline stocks is equally remarkable in relation to price when it is considered that total consumption for the year 1927 is almost exactly twice that of 1924. Clearly a new factor has been introduced. There is no possible factor to account for this distortion except known reserves of oil in ground storage, and therefore, until such time as the Bureau of Mines or the

* Consulting Economist.

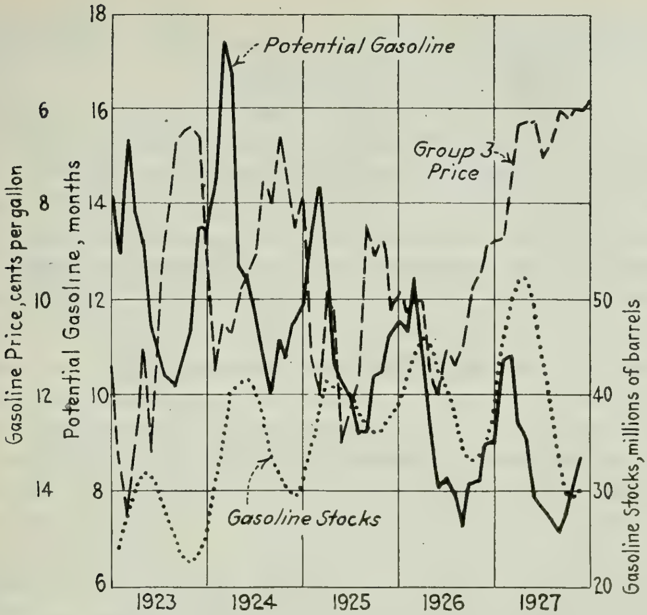


FIG. 1.—RELATION OF GASOLINE PRICE TO STOCKS BY MONTHS, 1923–1927.

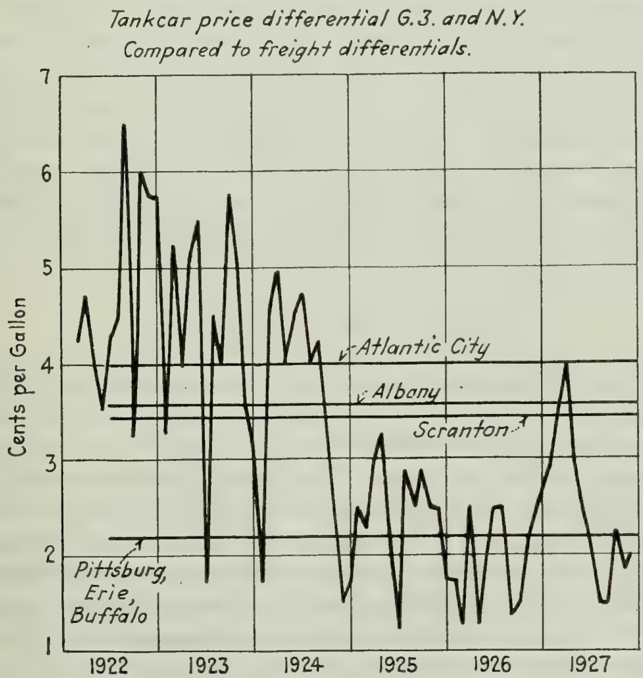


FIG. 2.—DIFFERENTIAL BETWEEN GROUP 3 AND BAYONNE TANK CAR MARKET FOR GASOLINE, BY MONTHS, 1922–1927.

American Petroleum Institute collect and publish regular figures for shutin production, the economist will continue at a disadvantage in justifying or forecasting the gasoline situation.

With the varying sources of supply and methods of making gasoline have come other changes in marketing and in relative prices. Fig. 2 is designed to show the changes which have taken place in the Mid-Continent tank car market, due to the excess gasoline of California. The curve shows the price differentials between tank car gasoline at Group 3 and at Bayonne: that is, the Bayonne price minus the Group 3 price. The horizontal lines show the rail freight differentials in cents per gallon, between Group 3 and Bayonne, to the places named; that is, the freight from Group 3 minus the freight from Bayonne. When the price curve is above the freight curve, it is cheaper to buy gasoline in Group 3; when below, it is cheaper to buy at Bayonne. Fig. 2 shows that due to the shrinkage of the price differential, the line of competition between Bayonne and Group 3 has been moved westward from Atlantic City to Pittsburgh.

There seems but little probability at present that East Coast gasoline will rise in relation to Group 3 gasoline, while it may easily decline further. So long as overproduction continues in California, West Texas and Venezuela it will require artificial manipulation of prices to raise the differential to its former level. California excess will continue available, subject to tanker rates. West Texas crude will continue to move largely to the coastal refineries of Texas and by tanker to the East Coast. Venezuelan crude can be delivered to East Coast cracking plants at less than $1 per bbl.; and the known fields of the Maracaibo basin are of greater potential importance than was Mexico in its prime. So long as this differential remains at its present level, the Mid-Continent refining industry is overbuilt, subject only to growth in Middle West demand and improvements in methods of marketing.

Spread in Price of Gasoline

The year 1927 has been remarkable for the wide spread which has existed between the Group 3 tank car price of gasoline and the posted tank wagon price. The amount of price cutting below the tank wagon price is also worthy of note. The spread explains better than any other single reason why some companies have been prosperous while others were losing money. The prosperous companies are those which have vast chains of bulk and retail stations and which sell little or no tank car gasoline. This condition is likely to change in the future, partly through the extreme competition which will precede the elimination of the weaker companies and partly through the expansion of the so-called bulk retail station.

Tank wagon prices are quite closely related to the Group 3 price over a long period as shown in Fig. 3, which presents conditions existing at Boston. The posted tank wagon price is here related to the cost of Group 3 gasoline delivered to the Boston retail station. The major swings of the two curves are alike. Averaging one figure per month shows that if shipping against the tank wagon price, Group 3 would have had an advantage of 0.59 of a cent during a 5-year period. In this

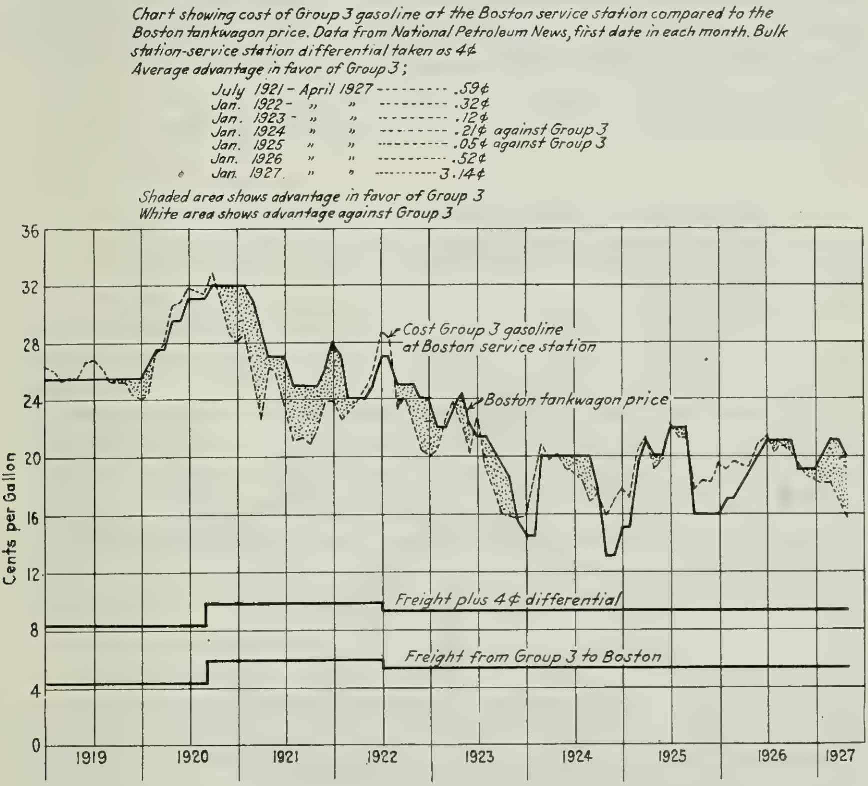


Fig. 3.—Relation between cost of Group 3 gasoline laid down at Boston and Boston service station price for gasoline, by months, 1919–1927.

comparison the tank wagon differential is taken as 4 c., which is generally considered a fair figure. The full rail freight from Group 3 is included, so that Group 3 could ship as far east as Boston if it only owned the necessary bulk and retail stations. If the companies which sell through their owned stations on this basis were equally considerate of each other in the matter of crude production, there would be no overproduction and the industry would be generally prosperous.

The fact that the industry has accepted the tank wagon differential as essential and has built bulk stations at inaccessible points to serve the

retail station at expensive locations, creates the opportunity of the cut rate bulk retail station. Such a station is simply one which has at least two tank cars of storage space and is located on a major highway on a railroad siding at the edge of a town. It eliminates the tank wagon cost. On the assumption that such a station can operate on 3 c., plus freight, plus the Group 3 cost, Fig. 4 shows at Boston, the relation of the posted tank wagon price to its retail price. The horizontal line shows the fixed cost of the station, that is freight plus 3 c. The curve shows the differential between Group 3 tank car gasoline and the posted tank wagon price at Boston. The result is a direct comparison between the bulk

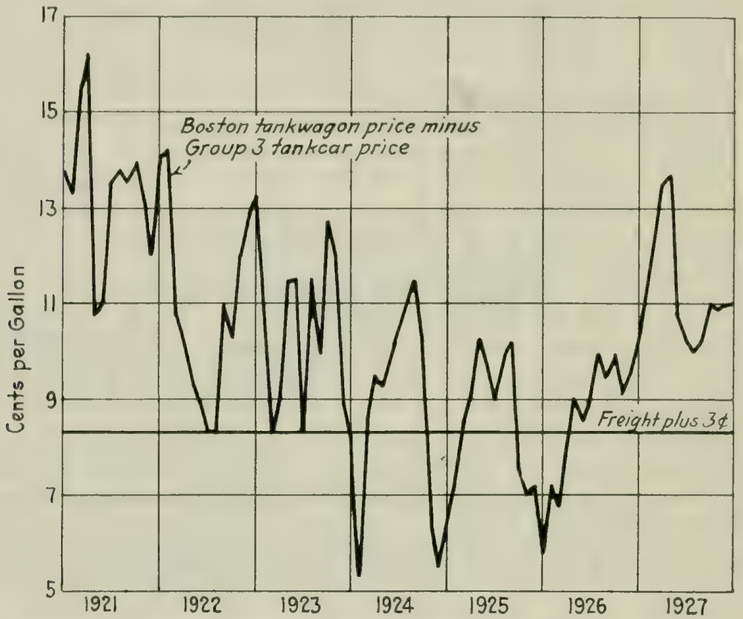


FIG. 4.—SPREAD BETWEEN BOSTON SERVICE STATION PRICE OF GASOLINE AND GROUP 3 TANK CAR PRICE, BY MONTHS, 1921–1927.

station retail price and the local tank wagon price. It is often true that the tank wagon price is lowered to large customers to just about the bulk station price.

Several of these stations have been described in various issues of the *National Petroleum News* during the past six months. They usually are found at the weak points in the general retail price structure. In many instances they are the cause of price wars, by which a great deal of local damage is done, both to the participating companies and to the industry in general by making the consumer distrust all prices because of their wide variation in different localities.

So long as the owners of retail stations are able to maintain retail prices which are artificially high in relation to the distress gasoline of the Mid-Continent and at the same time are greatly expanding their producing departments, there will be no true conservation of gasoline. The profits of transporting oil and gasoline at pipe line and tanker costs and retailing it on the basis of Group 3 plus rail freight can be used to great advantage in buying up properties and companies which are essentially insolvent due to the state of intense competition in crude production which the marketing departments consider necessary to the producing departments in view of the anti-trust law. If the producers operated as close to the anti-trust law as do the marketers when they buy up retail stations already in existence, there would be no overproduction of crude oil.

Future Supply of Cheap Group 3 Gasoline

In terms of present prices and methods of production, reserves of oil in known and prospective fields are small and almost certainly will be exhausted within a few years. As Mr. Pogue has well expressed an important economic fact, oil resources are a function of price and at any time are only that part of the ultimate resource which can be produced at the current price. On this basis there should be concern concerning the future supply of 6 c. gasoline in Group 3. The amount of oil which can be profitably produced at present prices is very limited. If the industry continues its course of producing at a loss, then it will find that sufficient companies will be eliminated from the situation to reduce production to the point where reserves will be increased through increased prices. There are many companies which will not be able to survive present prices for as much as two years.

In spite of this situation regarding the supply of cheap gasoline, the raw material of gasoline manufacture is being burned under boilers at prices which correspond to 5 c. gasoline in Oklahoma and 7 c. gasoline at New York. This destruction of cheap gasoline should be resented by every consumer, who should act through the various automobile associations to force reasonable conservation on the oil industry.

The cure for the difficulties of the oil industry lies not in legislation, which its advocates should know cannot be obtained in time to save considerable insolvency, but in a direct appeal to the Supreme Court for a final application of present law to present conditions. In spite of any amount of restraint which may exist in pipe line transportation, or refining or marketing, the decision must necessarily be that *in the production branch taken alone it is impossible for overproduction and restraint of trade to exist at the same time.*

In a similar way, and in spite of the Committee of Nine, gas and gasoline conservation can be secured by carrying to the Supreme Court a

case involving the rights of a neighbor and thus practically force the unit operation of oil pools. When gas is wasted, any neighbor's right of capture is damaged without due process of law, in that the percentage of oil within the reservoir which can be recovered is greatly decreased. The Supreme Court has never passed on a case of this kind where the full facts of oil production were involved. The American Petroleum Institute has provided ample expert testimony for the case in the Report of the Technical Sub-Committee of the Committee on Gas Conservation, published in Vol. IX, No. 2 of the Bulletin. The petroleum industry would lose nothing and gain a great deal through the decision which could certainly be obtained.

DISCUSSION

S. L. Gillan,* Los Angeles, Cal.—I want to refer briefly to the behavior of the price curve of gasoline in California in 1926–27. Commencing in the fall of 1926, the service station price of gasoline was $14\frac{1}{2}$ c. in Los Angeles, with the price of refining crude ranging from \$2.24 for 37° down to \$1.40 for 25° crude. The price of 37° crude was cut shortly thereafter to \$1.21 a barrel and for 25° to 90 c. a barrel. From the fall of 1926 until late in the spring of 1927, the corresponding curve for the price of gasoline shows an increase of 3 c. per gallon.

A. Knapp,† Philadelphia, Pa.—I think that price was accidental and coincided with the sale on the Atlantic seaboard of a large quantity of gasoline from California and its shipment through the Panama Canal. I do not think the exact situation would be duplicated again.

J. E. Pogue,‡ New York, N. Y.—There is an economic phenomenon well known in the export trade which is called "dumping;" at times when a commodity is in excess in a country they sell a distress volume to another country at a lower price than the price prevailing in the country of origin. Dumping may explain some of the peculiarities of the price movement in California.

---

* Geologist.

† Petroleum Engineer, The United Gas Improvement Co.

‡ Consulting Engineer.

Economics of Natural Gasoline

By D. E. Buchanan,* Tulsa, Okla.

(New York Meeting, February, 1928)

The volatility of a motor fuel is an index to its quality and to the satisfaction that will attend its use as an internal combustion engine fuel. Natural gasoline is concentrated volatility; therefore, it is quite natural that the most important market for natural gasoline should be for blending with less volatile refinery gasolines. Progress in the art of manufacturing natural gasoline, particularly in fractionation, which has made possible the elimination of the fixed gases and lighter hydrocarbons having a tendency to gasify at atmospheric pressure and temperature, has made it possible and desirable for refiners to utilize an ever-increasing percentage of natural gasoline in their finished product. This, in turn, has enabled the industry at large with each succeeding year to supply to the consuming public a better grade of gasoline.

While cracking processes and improved fractionation in refinery operation have resulted in higher yields of gasoline per barrel of crude oil refined, natural gasoline has also played a large part in this respect because it has enabled the refiner to cut deeper into the crude and still maintain proper standards of volatility by blending natural gasoline with the product from his stills. There is, of course, with even the present improved grades of natural gasoline, a limit to the percentage that may properly be used. This percentage varies with different grades of crude oil, varies according to the facilities employed at the refinery and varies according to the grade of motor fuel manufactured; therefore it is not possible to say that for a certain predetermined amount of motor fuel to be manufactured in a given area, a certain definite amount of natural gasoline will be required. It is, however, generally conceded, and statistics bear out the statement, that the average gallon of motor fuel sold in this country contains approximately 11 per cent. of natural gasoline. Isolated cases may be found where in a very few refineries during certain seasons no natural gasoline is used, while in other plants as high as 35 per cent. and 40 per cent. natural gasoline is used in certain grades of motor fuels.

Production Statistics

The total production of natural gasoline for 1927, including California, is estimated at 1,627,600,000 gal. This represents an increase of 20 per

* Vice President, Chestnut & Smith Corpn.

cent. over 1926. In fact, the increase has approximated 20 per cent. each year since 1924. During the last four years the area known as the Mid-Continent has produced an average of slightly over 60 per cent. of all natural gasoline produced in the United States and over 84 per cent. of the natural gasoline produced east of the Rocky Mountains. In 1927, the area east of the Mississippi river produced approximately 110,400,000 gal. as compared with about 107,000,000 gal. in 1924, an increase of only 3,400,000 gal. (32 per cent.) in three years. At the present time the refineries east of the Mississippi river are producing about 32 per cent. of our total motor fuel production while in that entire area there is being produced slightly less than 7 per cent. of the total natural gasoline production. The refineries of the Mid-Continent and Gulf Coast region (which is a logical market for Mid-Continent natural gasoline) produce less than 46 per cent. of our total motor fuel supply, but the Mid-Continent alone produces 86 per cent. of the entire natural gasoline production east of the Rocky Mountains. The Mid-Continent area produced 981,600,000 gal. of natural gasoline in 1927, as against 564,000,000 gal. in 1924, an increase of 417,600,000 gal., or 74 per cent. increase, in three years. It will be seen at a glance that the production of natural gasoline in the Mid-Continent field is considerably out of balance with the production of refinery gasoline and that the surplus must find a market in other refining territories.

Cost of Transportation

Natural gasoline must of necessity be manufactured at the point where the gas is produced and as it is used primarily for blending with refinery production it must, therefore, be transported by tank car to the refining centers which are located with more regard to centers of consumption or availability of cheap water transportation of finished products to the points of consumption. The character of the present established grades of natural gasoline precludes water transportation in bulk and it must be moved in tank cars to refining centers, in many cases under heavy freight rates. Whereas the value of natural gasoline is directly affected by the supply and demand of volatility, the price the refiner can afford to pay is governed in some degree by the sales price of his products. It can readily be seen that natural gasoline will not be in great demand by refiners on the East Coast at the present time, even at the very low prices prevailing today—approximately 5.5 c. f. o. b. Mid-Continent field—when the refiner is required to pay 4.75 c. per gal. freight for movement by tank car, bringing the delivered cost to 10.25 c. while U. S. motor is selling for 8 c. on the East Coast. It will be noted that for tank car shipments to Atlantic seaboard today the freight is equal to 86 per cent. of the value of the gasoline f. o. b. gasoline plant, or 46 per cent. of the delivered cost. We believe few commodities suffer this freight rate burden.

Need for Research to Develop New Products

The Research and Educational Campaign inaugurated by the Natural Gasoline Association of America two years ago has done much to acquaint the industry with the value of natural gasoline as a component of motor fuel, but this campaign has been centered upon the utilization of natural gasoline for this one purpose. The time has arrived when this applied research must be extended to other possible uses entirely outside the realm of internal combustion engine fuels. This also applies to the entire petroleum industry. No longer can the industry be content to produce crude oil and manufacture from it the products that have come to be known as standard and depend upon some other industry to make markets for those products. While some of the larger units in the industry have carried on considerable research in an effort to develop new products from petroleum, the industry as a whole has done practically nothing in this direction. Gasoline to us is motor fuel and that is about all. We must find entirely new uses for petroleum products and must find out what other products, unknown to us now, may be made from crude oil and then we must establish markets for those products.

We must do as other basic industries have done, notably the electrical, steel, rubber and cement industries. They are teaching us every day how to use the products of their manufacture in many diversified ways. They are not leaving it to us to develop diversified application of their products and then come to them for the supply. The petroleum industry has depended on the automotive industry to sell enough automobiles to use up the gasoline manufactured. When we find ourselves with a surplus we direct our efforts toward price cutting, hoping to take some of our competitors' business with never a thought to finding out if we might not apply some of our products to new uses or develop new products and a market to absorb them.

The natural gasoline industry, at least during the present condition of overproduction, is under the necessity of improving its products by the elimination of greater percentages of the low boiling point fractions which are the most undesirable in motor fuel. This naturally carries with it the necessity for finding some use for these volatile fractions. Not so many years ago crude oil was refined for its kerosene content and gasoline was considered a by-product. Today gasoline is the major product of petroleum. If the industry extends itself in the line of applied research, it is quite possible that in years to come the present-day by-products from the manufacture of natural gasoline, *i. e.*, isobutane, propane and even the lighter fractions, may be more valuable than the gasoline itself. The industry has learned something about the manufacture of chemicals from this alkyl series and the trend is toward further development in this direction but the markets for those products are now being adequately supplied from other sources. We must, there-

fore, develop entirely new uses for these products as we bring them into production. We have ruined our own business by overproducing every product of our manufacture and it is hoped that as we become more actively interested in perfecting processes capable of manufacturing entirely new products, we will at the same time concern ourselves with the matter of new uses for those products in order that we shall not extend our demoralization and flooding of markets to the detriment of the chemical or any other industry.

Production and Market Data, by Year

On the theory that the manufacturer of natural gasoline has nothing but concentrated volatility to sell, the following table showing the percentage of light oil, the production of natural gasoline per barrel of crude oil produced and the average price of Grade *A* natural gasoline in the Mid-Continent field for the past five years is of interest.

	Light Oil, Per Cent.	Natural Gasoline, Gal. per Bbl. Crude Oil Produced	Natural Gasoline, Mid-Continent Field,* Average Price Grade *A*
1923	82	1.15	$0.095
1924	76	1.30	0.089
1925	71	1.45	0.121
1926	82	1.78	0.096
1927	87.5	1.90	0.057

* Grade "*AA*" for 1926 and 1927.

The decrease in production of light oil from 82 per cent. in 1923 to 71 per cent. in 1925, may explain the increase in the average price of natural gasoline from 9.5 c. in 1923 to 12.1 c. in 1925. The increase from 1.15 gal. of natural gasoline per bbl. of crude in 1923 to 1.45 gal. in 1925, during the time of decreasing percentage of light oil, may be attributed to the utilization of casinghead gas for gasoline manufacture which had previously been considered unprofitable on account of its low gasoline content. It was during that period that improvements in manufacturing processes made it possible to process rather lean gas. The increase in light oil production from 71 per cent. in 1925 to 87½ per cent. in 1927, and the attendant increase in the ratio of natural gasoline to crude oil production from 1.45 gal. per bbl. in 1925 to 1.9 gal. in 1927, most certainly had all to do with the reduction in the average price of natural gasoline from 12.1 c. in 1925 to 5.7 c. in 1927. The prosperity of the natural gasoline industry seems definitely dependent upon the percentage of crude production classed as light oil. The writer, therefore, believes that the natural gasoline industry may anticipate some improvement over present conditions in the prospect for a decreasing percentage of light oil production, at least for this year.

We must not, however, be content with any temporary improvement that may result from this change but must bend out efforts toward finding entirely new uses for natural gasoline and for other products that may be manufactured either from natural gasoline or its by-products.

DISCUSSION

J. E. Pogue,* New York, N. Y.—The natural gasoline industry is of particular interest from an economic standpoint because it is a by-product industry and therefore the supply of the commodity is largely independent of price or demand and the situation is further complicated by the extreme volatility of the product which makes it difficult and costly to store.

E. R. Lederer,† Fort Worth, Texas.—I agree with Mr. Buchanan that it is essential that the natural gasoline industry, to survive, must cease being a by-product industry and become an independent industry. Research work along these lines has proved that the natural gasoline industry can be converted into a chemical industry. Great progress has been made in recent years, especially by stabilizing natural gasoline, so that the odium of having a carload of dynamite in the refinery has been taken away from natural gasoline. It is now as tame as any other product and the only trouble is loss in handling due to high volatility.

The industry has been able to separate out some of the wild hydrocarbons, especially isobutane and propane, and by proper and scientific distribution of these substances has been able to improve the quality of the finished products, in order to get ease of starting, acceleration and power. Furthermore, there is a possibility of separating a good many other hydrocarbons, chlorinating them for instance, or making alcohols out of these gases as is done successfully in the plants of the Union Carbide and Chemical Co. and others. The idea of trying to make the refiner use more casing-head gasoline than absolutely necessary is unsound. Another economic result along these lines was achieved by turning out products like "Naturline," and making a motor fuel especially good for aeroplane use and high-compression automobile motors.

J. E. Pogue.—The natural gasoline industry has taken a pioneer step in turning the force of technology from supply to the market.

---

* Consulting Engineer.

† Vice President, Pacific Coal & Oil Co.

An Economic Analysis of the Fuel Oil Situation

By Arthur Knapp,* Philadelphia, Pa.

(New York Meeting, February, 1928)

The economics of fuel oil must be considered in two aspects; viz., fuel oil as one of a number of competitive fuels and fuel oil as a refined product of petroleum.

"Fuel oil" is usually defined as that product of petroleum which is used in furnaces for the generation of heat by simple combustion. It is true that any product of petroleum used in an internal combustion engine is essentially a fuel oil, but such oils are not included in the class known as "fuel oil."

Fuel Oil as One of Several Fuels

For a number of years, the petroleum industry has believed that the petroleum reserves were very limited and that petroleum products would begin to become scarce within a few years. The industry has believed

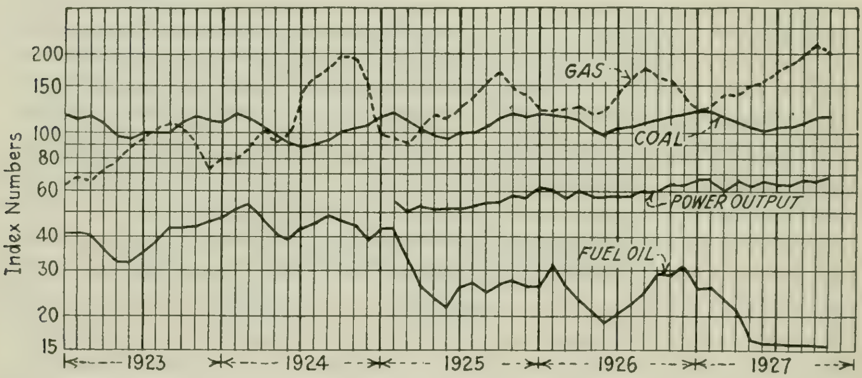


Fig. 1.—Daily average consumption of fuels by public utility power plants.

that there would be a gradual but continual rise in prices as a result of this impending scarcity.

The industry, therefore, has informed the users of fuel oil that, once they were eliminated by price, they were eliminated for all time. The petroleum industry believed and made the consumer believe that there would never be any appreciable recession in price which would make it

* Petroleum Engineer, The United Gas Improvement Co.

worth while for any consumer of fuel oil to resist elimination with the expectation of future lower prices.

The effect of this attitude toward the future of the fuel-oil market is shown by the trend of consumption of fuel oils by the railroads and by public utility power plants generating electric power.

On Fig. 1 are plotted the fuels consumed by public utility power plants. The decrease in the fuel oil used may be partly the result of increased efficiency of use. If the price of fuel oil alone was the factor governing the major portion of the decreased use, the curve of consumption should bear some relation to price. However, the major influence has been the fears of the consumers that fuel-oil prices would continue to rise, and they have offered no resistance to elimination as fuel-oil users as soon as the price became too high.

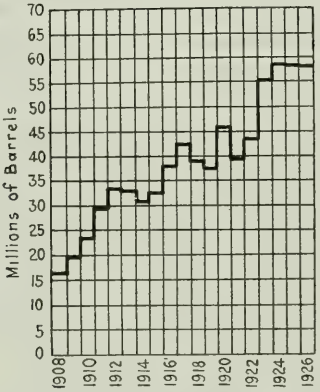


Fig. 2.—Fuel oil consumed by railroads.

Fig. 2 shows the consumption of fuel oils by railroads. The railroads have had the same feeling regarding the fuel-oil situation as have the public utilities. The increase in the efficiency of use, which has been brought about by the railroads, would have built up considerable resistance against elimination had the railroads been given reasonable assurance that price recessions might be expected.

The railroads and public utilities producing electric power together consume at least a quarter of the fuel oil marketed. They have a common problem of purchasing. They cannot make immediate adjustments of the selling prices of their services and are, therefore, primarily interested in a stable market. They require long-time contracts and these are the principal reasons why they have been more interested in coal than in oil.

Another 20 per cent. or more of the fuel oil produced is consumed as bunker oil. The intensive competition to be found in ocean transportation, coupled with the slowness with which it is possible to adjust ocean freight rates, make it imperative that shipping companies shall also have a stable fuel market.

Another 10 per cent. of the fuel oil produced appears in the statistics as exported. The greater part of this is also used in vessels and may be considered under the heading of bunker oil.

In other words, over half of the fuel oil sold is sold in competition with coal and gas, not only on a cost basis, but also on the basis of stable markets and long-term contracts.

The petroleum industry uses at least one-eighth of the fuel oil produced. Even in this use, coal is sometimes a competitor and gas is coming more and more into use, to the elimination of fuel oil. Petroleum coke is also a competitor.

About 16 per cent. of fuel oil is consumed without severe competition at the present time because of its superior qualities in heat treating, smelting, cement burning, etc. This is a passing phase, as gas and powdered coal are being developed and will be serious competitors of fuel oil, particularly in large plants. The plant investment required for gas production or powdered coal use has been a handicap which is being overcome.

Of the remaining 20 per cent. (approximately), the gas companies consume about 6 per cent. in the production of manufactured gas. The manufactured gas industry as a consumer is gradually being eliminated by improvements in process. These improvements are the result of research under the threat of a continual increase in price.

About 4.5 per cent. is used for heating houses and office buildings. Coal is not a serious competitor of fuel oil for heating office buildings, because of the extreme convenience of oil as a fuel. For dwelling houses, coal is always a competitor except for those who can afford to pay for the convenience of oil fuel. Domestic gas is coming more and more into the field and as soon as gas distributors can find some economic solution to the problem of overload which gas house-heating produces, domestic gas will be a serious competitor of fuel oil for heating dwellings.

Fuel Oil as a Petroleum Product

Fuel oil occupies a unique position among petroleum products since it is, in general, the residue of refining operations. It is also unique in that increased efficiency within the industry nearly always results in a decrease in the consumption of fuel oil. The use of gas under field boilers and the electrification of drilling and production operations result in fuel-oil economy. The use of refinery gas under stills and the introduction of heat exchangers result in further fuel-oil economy. The use of internal combustion engines for drilling, pumping wells, pipe line pumps, and tanker propulsion, all mean less fuel oil consumed.

Only one thing has worked toward a decrease in the fuel oil available for marketing, and that is cracking. The overmanufacture of gasoline has been so extensive and so prolonged, however, that the economic

balance between outputs and prices of gasoline and fuel oil has never been established.

Fig. 3 shows the ratio of fuel-oil price to gasoline price in Group 3 territory during the past five years. The trend of this ratio is upward, showing that fuel-oil prices have consistently increased as a proportion of gasoline prices over this period. It is doubtful if the economic relation of these prices is a proportion. It is more probable that it is a difference.

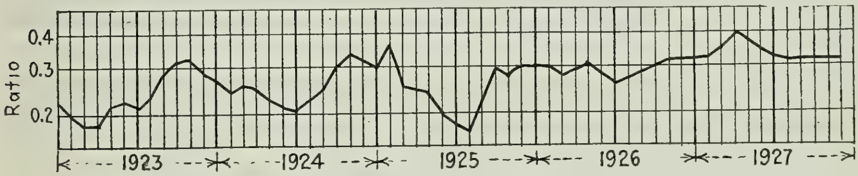


FIG. 3.—TREND OF RATIO OF FUEL OIL PRICE TO GASOLINE PRICE.

Fig. 4 shows the difference between the price of gasoline and that of fuel oil and gas oil in Group 3 during the past five years. Previous to the advent of cracking, there was a wide difference in price between gasoline and fuel oil, a difference that declined rapidly to an amount approximately equal to the relative value of fuel oil as such or as gasoline. This relation has not held in 1927 because of the general demoralization of both markets. During the past year, the difference has been decidedly in favor of selling fuel oil as such rather than cracking it into gasoline.

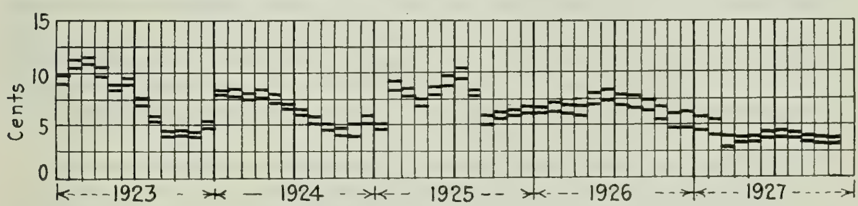


FIG. 4.—DIFFERENCE BETWEEN GROUP 3 GASOLINE PRICE AND FUEL OIL PRICE (UPPER LINE). DIFFERENCE BETWEEN GASOLINE AND GAS OIL (LOWER LINE).

STATISTICAL ANALYSIS

It is impossible to go much further into the economics of fuel oil because of the lack of detailed statistics. Fig. 5 shows the net stock changes of gas oil and fuel oil held at refineries east of California as reported by the American Petroleum Institute. In the past three years 16,456,000 bbl. of gas oil and fuel oil have been added to the accumulations of the previous years (to Dec. 1, 1927). This is 50 per cent. of the total stocks of all oils accumulated by refineries during these three years. During this same period, there was a draft of 1,923,000 bbl. upon the stocks of gasoline previously accumulated.

It is impossible to make an accurate statistical analysis of the national situation. All classes of fuel oils are reported under one heading and, in addition, California non-refinable crudes are reported with the fuel oils of that region. Because of the extreme flexibility of modern transportation, particularly ocean transportation, the national situation should be considered, and it is unfortunate that more detailed statistics are not available. It would be particularly useful if all fuel oils close to the seaboard could be considered in one study but such statistics are not available except under a general heading which includes all classes of gas oils and fuel oils.

Of the volume of all fuel oils in storage east of the Rockies, about two-thirds is held in regions bordering on the seaboards. This proportion has been almost constant for the past two years.

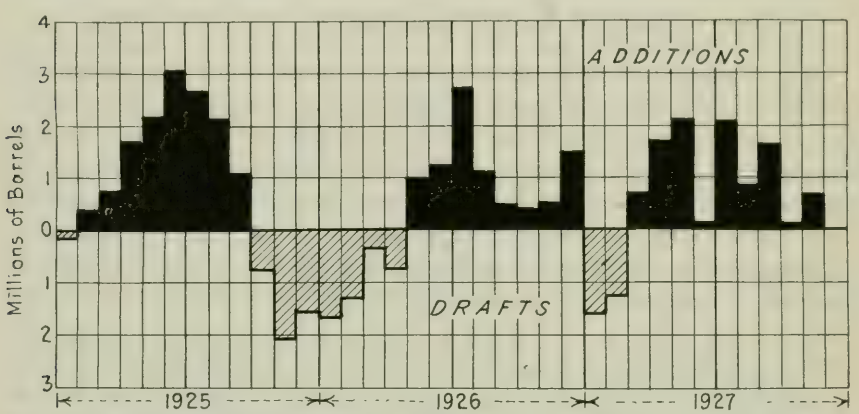


Fig. 5.—Fuel-oil storage east of the Rockies. Monthly additions and drafts, A. P. I.

Conclusions

It is evident that the sales of fuel oils must be accelerated until they can keep pace with the other petroleum products. An increase in gasoline and kerosene sales would accomplish the same result to some extent through the elimination of some of the fuel oil by cracking. The possibilities for appreciably increasing the sale of these products does not appear to hold out as much promise as does the field of possible increase of fuel oil sales. The recovery of former fuel-oil customers would furnish an outlet for a large volume now without a market.

Real sales effort will be necessary in order to sell fuel oil in competition with other fuels. More attention will have to be paid to external competition and less attention to intensive competition within the industry.

It may be necessary to resort to research for new uses for petroleum products in general and fuel oils or the heavier oils, in particular. The

industry has been out of balance since its inception, through having one product which was considered as the principal product. Kerosene was the first "principal product." Later gasoline took its place. During the past year or more, the tide has swayed between gasoline and fuel oil. The industry will never reach stability until there is a balance of demand for all petroleum products. The industry should accelerate the approach of this balance by research into new uses.

Better balance could be obtained under present conditions by proper regulation of outputs and by proper merchandising. By "proper merchandising" is meant a proper relation between price and output in order to bring a close balance of the volume of sales of the various products. Proper merchandising also means a proper attitude toward the relation of the price of crude stored to cover contracts and the price of refined products sold under these contracts.

The industry is severely handicapped by a lack of more detailed fuel-oil statistics. The problem of marketing the current output of fuel oil and of reducing the present large stocks is a very serious one. The need of accurate and detailed statistics covering fuel oils is evident.

DISCUSSION

E. B. Swanson,* Washington, D. C. (written discussion).—Mr Knapp emphasizes the need for detailed fuel oil statistics. Recognition of this need by the Bureau of Mines and the American Petroleum Institute resulted in cooperative arrangements to study the industrial and geographical distribution of fuel oil. Reports have been issued covering fuel oil deliveries on the Pacific Coast during 1924, 1925 and 1926; the Atlantic Coast during 1925 and 1926; and national fuel oil distribution during 1926. The national survey of fuel oil distribution during 1927 is now well under way. In these surveys the Bureau and the Institute have received the complete cooperation of the petroleum industry.

The national survey, covering fuel oil distribution during 1926, brought out these facts:

1. The use of oil as an industrial and commercial fuel is concentrated in the south central and southwestern states, where adequate supplies of fuel oil are available, but commercial deposits of coal are accessible only by a long railroad haul.

2. One-third of the fuel oil marketed was exported or left the country as bunker oil on ocean-going vessels, while two-thirds was delivered for various shore uses. Only one-fifth of the quantity delivered for shore uses was marketed in the interior states; four-fifths of the domestic consumption being credited to the seaboard states. The refining of petroleum and the resulting production of fuel oil is concentrated in the seaboard states, California, Texas, Louisiana, Pennsylvania, New Jersey and New York, six states which account for 70 per cent. of the total fuel oil deliveries.

3. Four per cent. of the total consumption was met by natural heavy crude, burned in its raw state without refining; 6 per cent. by foreign crude and fuel oil; and 90 per cent. by gas oil and fuel oil produced in United States refineries from domestic and foreign crude petroleum.

4. Nearly three-fourths of the crude petroleum put through stills in 1926 was refined to such a point that the gas oil and fuel oil production was 38 per cent. of the crude refined; for the remaining one-fourth, the gas oil and fuel oil recovery was 70

* Economic Analyst, Bureau of Mines.

per cent. The first group, refining 73 per cent. of the total, produced 59 per cent. of the national production of gas oil and fuel oil, whereas, the second group, refining 27 per cent. of the crude, produced 41 per cent. In the matter of fuel oil production, the country can be divided into two sections—California and East of California. In California during 1926 fuel oil demand was nearly in balance with production. East of California the average production of gas oil and fuel oil per barrel of crude refined was approaching its economic limit and foreign oils were imported to meet the fuel needs.

5. The following table shows the major fuel oil consuming industries, as reported in the survey mentioned:

NATIONAL DISTRIBUTION OF GAS OIL AND FUEL OIL, 1926

Uses	Barrels	Daily Average, Barrels	Per Cent.
Railroads	74,703,869	204,668	19.7
Bunker oil, including tankers	78,932,016	216,252	20.8
Gas and electric power plants	33,022,921	90,474	8.7
Smelters and mines	9,142,964	25,049	2.4
Shipbuilding, steel mills and foundries	16,102,458	44,116	4.3
Automotive industries	1,457,398	3,993	0.4
Sugar refineries	2,852,858	7,816	0.8
Logging and lumbering	3,185,268	8,727	0.8
Cement and lime plants	5,586,144	15,305	1.5
Brick and clay plants	3,216,692	8,813	0.9
Food industries	4,717,435	12,924	1.2
Other manufacturing	24,467,780	67,035	6.5
Commercial heating	14,266,026	39,085	3.8
Domestic heating	2,803,789	7,682	0.7
U. S. Navy, transports and Coast Guard	6,540,410	17,919	1.7
Oil companies as fuel	48,845,896	133,824	12.9
Miscellaneous uses	7,306,304	20,017	1.9
Non-segregated distribution by jobbers	3,330,621	9,125	0.9
Exports and shipments to U. S. territories	38,351,000	105,071	10.1
Total distribution	378,831,849	1,037,895	100 0

G. O. SMITH,* Washington, D. C.—It seems to me that one of the chief difficulties which the petroleum industry faces at the present moment is efficiency. We know that the production engineer has become too efficient in getting oil out of the ground. The flood of oil speaks for itself and now it seems that there has been a bit too much efficiency shown by the combustion engineer in making other fuels such good competitors of petroleum. We are blessed by our efficiency, but it is rather hard on prices. I do not know just where this thing is going to end. Of course, I still rely on the obvious fact that whenever we take some oil out of the ground, it is no longer there to take out again. That part of our fundamental premises still stands.

J. E. POGUE,† New York, N. Y.—Fuel oil certainly presents a peculiar problem to the petroleum industry because if we wish to continue to overproduce crude oil, it is certain we must expand the market for fuel oil and to do the latter is not consistent with our professions of conservation, so that leaves us, it seems to me, in a dilemma.

* Director, U. S. Geological Survey.

† Consulting Engineer.

Chapter XVI. Crude Petroleum

Economic Significance of the Oil Developments of West Texas

By C. P. Watson,* Fort Worth, Texas

(New York Meeting, February, 1928)

Economics has been defined as the useful application of wealth or material resources. The search of alchemists in the Middle Ages for a formula by which base metals might be transmuted into gold was no more intensive than has been the search by all branches of the oil industry for methods whereby the material resources of West Texas in the nature of sulfur-bearing oil might be usefully applied. The purpose of this paper is to present in brief space developments that are conceded to possess economic significance.

History

The first discovery of oil in commercial quantities in the Permian Basin of West Texas was the Westbrook field in Mitchell County in 1920. Three years later the discovery well in the Big Lake field was completed as a small pumper (70 bbl.) at a depth of 3028 ft. In 1925, discovery of the Powell or World pool in Crockett County stimulated activities in the Permian Basin, further establishing the importance of the Permian limestones as sources of production. The years 1925 and 1926 were marked by a period of extensive leasing and drilling activities. At the close of 1926 more than 7,000,000 acres had been leased and discovery wells completed in the Hurdle, Hendricks and Yates fields, definitely establishing the importance of the Permian Basin as a source of production from free-flowing wells.

Review of Fields

The producing fields in the Permian Basin are grouped on three distinct lines of folding. These may be separately identified as the Big Lake-Powell fold; the Yates, Hurdle, and Church-McElroy area and the Winkler County development.

Production is derived from a porous limestone stratigraphically uniform, encountered at depths varying from 900 to 3100 ft. Lenticular sand bodies above the lime in Howard County have resulted in the

* President, Federal Royalties Co.

development of shallow fields with daily output of 6000 bbl. These irregular sand bodies are characterized by wells of small but stable yield.

Big Lake

Estimates of future recoveries from West Texas fields may be predicated with refinements for local conditions on the past performance of the Big Lake field. Developments thus far in the field have resulted in the drilling of 203 producing wells with a total yield of 28,460,000 bbl. to Jan. 1, 1928, or 140,000 bbl. per well. The proved area of the field is placed at 3500 acres, and proved undrilled locations at 196. Initial pressure of the field has declined and all wells are now being pumped. Estimates of acreage recovery for the field have been placed at 25,000 bbl. per acre.

Yates

The discovery well in the Yates field was drilled Oct. 29, 1926. The surface structure shows two highs with NW-SE strike. The producing zone is a brown dolomitic limestone with drilled thickness to date of 350 ft. thinning towards the edges of the field. A free gas horizon is found in the highest part of the field but its consideration is not warranted from any economic point of view. Water is known to underlie the structure and surround it at a more or less uniform depth, exerting a hydrostatic head of approximately 700 pounds.

The expelling medium of the oil is essentially a water drive requiring careful check and restraint to prevent water coning at the bottom of the well. The initial production of wells based on hourly gages has established a potential output of 600,000 bbl. per day, the attainment of which figure over a 24-hr. period is neither probable nor possible as it has been recognized by operators in the field that production methods will require restricted flow to prevent rapid water encroachment.

Pipe-line outlet from the field is approximately 50,000 bbl., which has been allocated to each producer in the percentage that his proved acreage bears to the whole proved area. These figures, comparing January and February allottments, are as follows:

	Dec. 1, 1927		Feb. 1, 1928	
Companies	Proved Area, Bbl.	Pipe Line Percentage	Proved Area, Bbl.	Pipe Line Percentage
Mid-Kansas Transcontinental	4,833.6	32.17	5,163.20	35.25
California	3,279.73	15.28	2,361.30	16.75
Gulf	2,599.13	16.13	2,490.80	17.68
Roxana	1,651.19	8.82	1,361.70	9.67
Humble	1,216.32	7.18	1,109.12	7.87
McMan-Marland	697.13	8.00	697.13	4.95
McMan Oil & Gas				1.59
Simms Oil	393.35	6.00	393.35	2.79
Red Bank Oil	140.00	1.00	133.00	0.9433
Marland Oil	119.35	2.00	119.38	0.8476
Kirby-Edson	80.00	0.82	85.00	0.8168
Savoy-Mazda	80.00	0.50	80.00	0.5680
Osage Oil and T. T. Word			2.00	0.2769
Pandem Oil Corpn. and Gibson	24.00	0.50	39.10	0.2769
Totals	15,113.80	100.00	14,259.17	100.00
Undeveloped proved acreage	1,663.31		504.89	
Grand total	16,777.11		14,764.06	

The shallow depth at which production is encountered renders drilling costs extremely low in this field, with wells completed and equipped for production at unit costs of $12,000 to $15,000. Low drilling costs and large initial production from free-flowing wells are factors which viewed with respect to the proved area render this field notable in the development of West Texas.

Estimates of ultimate yield vary from 250,000,000 to 500,000,000 bbl. In the absence of any historical background and with little or no knowledge about the rate of water encroachment it would appear conservative and logical to accept the lower figure of 250,000,000 bbl. to be won from 15,000 acres.

Church-McElroy

Total production from the Church-McElroy field to Jan. 1, 1928, now identified as one continuous producing structure, was 24,100,000 bbl. from 216 wells. Well spacing has been on the basis of one well to 10 acres with a recovery of 11,000 bbl. per acre. Knowledge of the productive limits of the field remains at this time unknown. In the McElroy section of the field under lease to the Gulf Production Co. approximately 8000 acres are proved but only partially exploited with accretions to this latter figure highly probable as drilling is extended along the axis of the structure. Individual lease records show acreage recoveries as high as 34,000 bbl. to date.

Hendricks

The Hendricks field located in Winkler County reached a total of 95,000 bbl. daily in output at the close of the year almost coincident with the appearance of water in several wells throughout the field. Development of the field to date has demonstrated a producing zone approximately 600 to 700 ft. in thickness with varying degrees of porosity and suggested evidences of fissuring in the limestone. The highly irregular features encountered in the producing history of this field warrant the assumption that a field of major importance in an ultimate sense is in course of development. The limits of the field on the south and west have been established by dry holes or water wells. The data at hand are insufficient to determine the eastern and northern limits. The present producing area embraces 8000 acres on which 48 producing wells have been drilled. Southern Crude Oil Purchasing Co.'s well No. 1, Sec. 4, Block B-12, has recorded a total production in excess of 700,000 bbl. since its completion in September, 1927, and continues to flow free of water at the same rate as when completed, notwithstanding its greater depth than structurally higher wells showing water encroachment. Individual wells with briefer producing histories have demonstrated similar capacities for uninterrupted and sustained output. Individual well achievements are not numerous enough at this writing to establish criteria by which reasonably competent estimates of field performance may be reached. Present knowledge of developments may justify an estimate of 15,000 bbl. per acre.

Hurdle

The Hurdle district in Crane and Upton Counties, the Westbrook field in Mitchell County and the Powell field in Crockett County conclude the list of actively exploited fields producing from the Permian limestones. The immediate association of water with the oil in the Hurdle and the Powell fields has served to characterize this type of production as exceedingly stable and uniform, emphasizing the importance of bottom waters as a flushing medium in limestone beds.

Characteristics of West Texas Crudes

The physical properties of West Texas crudes are such as to create greater expense in transportation, storage and refining. The many problems involved in the treatment of this oil in refineries has led to serious consideration of the economic value of these higher sulfur-bearing crudes. However, it need not be emphasized that price and supply are two fundamental factors working towards a hasty solution of these problems. The volume of oil being placed in steel storage and the

amount reaching primary markets may be accepted, in the absence of more positive evidence, as indicating partial solution of the problems.

The presence of varying amounts of sulfur in the oils and the occurrence of hydrogen sulfide gases have imparted to the oil produced from the limestones in West Texas the term "sour crudes." Analyses showing the physical properties of these crudes are as follows:

Analyses of West Texas "Sour Crudes"*

Field	Gravity, Deg. A. P. I.	Sulfur, Per Cent.	Gasoline, Per Cent.	Kerosene, Per Cent.	Gas Oil, Per Cent.	Lubricating Oil, Per Cent.	Distillation Residues, Per Cent.
Big Lake	38.2	0.36	32.8	9.8	13.7	17.5	24.9
Chalk	32.1	0.84	25.0	9.5	15.4	17.7	31.5
Church-McElroy	31.1	2.40	26.6	9.6	14.5	19.9	25.9
Hendricks	30.0	1.53	22.7	5.6	81.4	22.3	29.7
Yates	30.0	1.61	22.2	5.0	18.5	26.8	25.7
Westbrook	25.2	2.68	27.3	13.3†			
Upton County	31.0	2.56	25.1	3.0†			

* Samples analyzed under direction of E. C. Lane at Bureau of Mines Experiment Station, Bartlesville, Okla. See *Oil & Gas Jnl.* (Jan. 12, 1928) 30.

† C. K. Francis: Refining West Texas Crudes. *Oil & Gas Jnl.* (Nov. 17, 1927).

Unfavorable criticism of the physical properties has been directed in turn to crude oils of nearly all newly discovered fields. A report to the Oklahoma Corporation Commission on oil from the Healdton field in 1913 stated: "The oil lacks vitality and it goes to pieces very readily; meaning that the volatile ingredients are lost, leaving it rather thick, dead and sticky. There is a very perceptible sulfur odor noticeable over the field, like that where the heavy crudes are produced in Texas, Mexico and California. These superficial data also indicate that the Healton production can easily be rated as a fuel oil in contradistinction to a refining oil."

Smackover was acceptable solely as a fuel oil while Mexia crude was viewed with some degree of alarm due to the high temperature and quality of the oil. The former is now yielding a total of 40 to 45 per cent. gasoline whereas the properties of Mexia crude have been found to contain excellent cracking stocks with demonstrated values equal to some of the best Mid-Continent crudes. Processing Panhandle oil through topping and pressure stills give yields of 28 to 32 per cent. U. S. motor gasoline with anti-knock values,[1] with estimated comparative costs of 23 to 28 c. more per bbl. for treatment than similar grades of Mid-Continent crude.

[1] Walter Miller: Refining Panhandle Crude. A. P. I. *Bull.* **8**, No. 6, 309 (1927).

Corrosion

Corrosion of metal is essentially an electrochemical process accomplished through the agency of water. The most vigorous corrosive agencies are hydrogen sulfide and sulfur compounds which are contained in varying amounts in West Texas oil. Corrosion in the field is particularly noticeable in the decks of storage tanks, settling tanks and surface equipment containing brass or bronze fittings. Purification plants have successfully treated the hydrogen sulfide gases at a cost of 1 to 5 c. per 1000 cu. ft. rendering the treated product free from toxic and corrosive action.

Refinery experiments have found that corrosion is an action dependent upon the chemical composition of the sulfur compounds rather than the amount of sulfur present. In this connection, crude from the Luling field with less than 1 per cent. sulfur content has been characterized as the "worst corroding oil of any produced in the United States."

Transportation

Trunk line outlet from West Texas fields through pipe lines to primary markets is approximately 140,000 bbl. daily. Outlet through tank car shipments is strictly limited by facilities provided by the railroads. Aggregate capacity of loading rack facilities is approximately 600 cars daily of 200 bbl. each. Estimates of shipments by tank cars indicate total outlet through this source will vary between 100,000 and 150,000 bbl. daily for the year 1928. Facilities at present completed will provide for an additional 60,000 to 80,000 bbl. per day outlet to storage tanks within the area. Since it is through direct market outlet that new areas exert any economic importance we find that West Texas oil is restricted in its market influence to that amount for which a primary market outlet exists. Available information indicates outlets to be as follows:

	Bbl. Daily
Trunk line outlets	140,000
Maximum tank car outlet	140,000
Local refinery demand	20,000
	300,000
Trunk line outlets building*	40,000
	340,000
Outlet to tank farm storage	70,000
	410,000

* Will be complete about Aug. 1.

The volume of West Texas oil reaching primary markets is therefore limited to approximately 310,000 bbl. daily for the first six months of

1928. In the second half of the year increased facilities will provide an additional estimated outlet of 50,000 to 70,000 bbl. daily.

Influence of West Texas Oil on Other Markets

There can be no denial of the market influence created by a series of producing districts whose potential possibilities, although measured by new standards, have some basis of calibration. The producing areas of West Texas are found superimposed on more or less parallel structural features 50 or more miles in length. On these definitely established trends, notwithstanding the vagaries of structural geology, one or more additional fields of magnitude may be assumed. A development, at present limited in its economic importance, strongly suggests the future exploitation of sand production along the flanks of the Winkler County "high." The Llano-Roxana and Texas Rhoades wells, the latter in Southeastern Lea County, New Mexico, offer the most logical explanation of this occurrence of oil. A broad consideration of the future possibilities of the Permian Basin inclines a thoughtful person to the belief that perhaps under such conditions as are in existence an active agency towards stabilization has been created and that the oil resources of this area will reach useful application in orderly amounts.

Values

The posted price in the field for all grades of West Texas crudes, except Big Lake, is 60 c. per bbl. Transportation costs for the movement of this oil, the bulk of which is afforded an outlet to primary markets through Gulf Coast ports, are shown to be:

Pipe line (gathering and delivery charge)	$0.48 to 0.55
Tank car (includes car rental*)	0.60 to 0.78

* Rates are based on export shipments to foreign and Atlantic Coast ports.

Base Rates

Origin	Destination	Cost per Bbl.
Oklahoma	North Atlantic Ports	$0.7675*
West Texas	North Atlantic Ports	0.6500*
Panhandle	North Atlantic Ports	0.8000*

* Does not include gathering and delivery charge.

Tank Car Rates

West Texas	Texas Gulf Ports	0.6000*
Oklahoma	Texas Gulf Ports	0.5580
Panhandle	Texas Gulf Ports	0.6200

* Approximate.

A comparison between the costs of West Texas crudes and Seminole crude at North Atlantic ports is considered of sufficient interest to warrant the expression of values as indicated herewith:

	Seminole	West Texas
Field price	$1.36	$0.60
Transportation*	0.7675	0.65
	$2.1275	$1.25

* Does not include gathering or delivery charge.

The lower rate for West Texas crude is created by unseasonably low water rates from Gulf Coast ports to North Atlantic ports.

Refining Values

Competitive factors have determined the differential at which new supplies of crude will move in competition with oil from established fields close to sources of consumption. Based on the results of an investigation by the Federal Trade Commission, this differential for Panhandle oil has been estimated to be approximately 35 c. per bbl. The physical properties and characteristics of West Texas crudes have rendered the utilization of this oil adaptable only in special types of equipment. Small plants designed to operate on less refractory types of crude oil have found that treatment of West Texas oils carries with it an excessive penalty for depreciation. Restriction, in the future, to plants especially equipped to process this oil is a warranted conclusion which, however, does not reflect tendencies toward greater utilization justified by assurances of a large supply. The answer to the question, "What influence will West Texas have on the price structure?" involves many considerations and variable factors. Some, however, may be treated in broad outline and include:

1. Large supply of oil available for future use.
2. Differential of 20 to 30 c. per bbl. due to presence of sulfur compounds.
3. Extraction of 22 to 28 per cent. gasoline, high in anti-knock compounds, through straight distillation and a maximum of 32 to 38 per cent. gasoline extraction through atmospheric and pressure distillation.
4. Improved refinery technique allowing treatment of "sour crudes" at lower costs.
5. Use of "sour crude" restricted and limited to special equipment.
6. Volume restricted in 1928 by pipe line facilities.

Mid-Continent crude oil of similar gravity to crude oils from the Yates, Hendricks and Church-McElroy fields—30° to 31° A. P. I.—has a posted price of $1.16 per bbl. as compared with 60 c. per bbl. for West Texas. The value of these oils of Gulf Coast and North Atlantic points is as follows:

Gravity	Gulf Coast	North Atlantic
Mid-Continent, 30° to 30.9°	\$1.70	\$2.12
West Texas, 30° to 31°	1.25	1.55

Unfortunately, sufficient data are not at hand to determine the relative refinery value of various crude oils of similar specifications at common points. With the less variable factors of crude oil prices and transportation rates to common points, comparative values indicate that an equilibrium may be assumed and that reductions in price of West Texas crude will result in the greater encroachment of markets at present denied "sour crudes."

Typical skimming plant operations on several grades of West Texas crudes and one sample of North Texas sweet crude based on Fort Worth markets indicate results as follows:

Values, North and West Texas Crude Oils

	North Texas	Reagan County	Winkler County
Gasoline	\$1.05	\$0.957	\$0.52
Kerosene	0.22	0.034	0.13
Gas oil		0.170	
Fuel oil	0.50	0.319	0.73
	\$1.77	\$1.480	\$1.38
Freight	\$0.375	\$0.50	\$0.54
Refining expense	0.150	0.15	0.20
	0.525	0.65	0.74
Refining value	1.245	0.83	0.64

Summary

1. To Jan. 1, 1928, the Permian Basin had produced a total of 76,753,000 bbl. from 45,764 proved acres and 1168 wells.

2. Estimates of future production from exploited fields are distributed as follows:

	Bbl.
Yates	325,000,000
Church-McElroy	180,000,000
Big Lake	65,000,000
Hendricks	120,000,000
Miscellaneous	25,000,000
Total	715,000,000

3. Outlet to primary markets through pipe lines and tank cars for the first half of 1928 will not exceed 310,000 bbl. daily with a maximum of 400,000 bbl. per day by the end of 1928.

4. Costs of transporting this oil to Texas Gulf ports are 48 to 55 c. through pipe lines and 60 to 68 c. by tank cars.

5. Drilling costs vary between $12,000 in the Yates field and $35,000 in the Hendricks field.

6. Production expenses for one group of properties have varied between 3 c. per bbl. during flowing stages and 10 c. per bbl. during pumping stages.

7. Extensions to the Hendricks field and evidences of a new field north of the Church-McElroy are the most significant developments at present.

Conclusions

The volume of West Texas crudes competing with sweet crudes is, at present, limited to outlets and plants equipped to treat these sour crudes.

Additional costs involved in rendering refined products, derived from sour crudes, sulfur-free, impose additional refining expense.

"Sour crudes" from West Texas and Panhandle fields furnished approximately 9 per cent. of the total crude oil production of the United States in 1927.

The increasing importance of these areas as sources of production which has been found to contain a higher percentage of sulfur compounds than other oils, assures the refining industry of future supplies to warrant the necessary changes in equipment.

Prices for these crudes will be a function of demand at present restricted and defined. Processing this oil will require fundamental changes in equipment and plants.

DISCUSSION

F. J. Fohs,* New York, N. Y.—Mr. Watson's estimate on the future production of the Yates pool is too high—in fact, about 50,000,000 bbl. too high—although the West Texas producing pools now opened may ultimately yield the total he names. Predictions of a year ago that West Texas would have a potential reserve, including Panhandle, of 3,000,000,000 bbl. can now be discounted for wildcats of the year have eliminated much territory. Thus we can eliminate the southern half of Pecos County, Terrell County, practically all of Crockett, Val Verde, Reeves, Loving and Brewster counties, as areas having large flush producing pools. The northern half of Pecos has also been badly hit and new pools therein are now limited to a few deep possibilities. Additional possibilities occur in Ward, Winkler, Upton and Ector counties of Texas and in Lea County in New Mexico, but the pools of major areal size with, perhaps, a few exceptions in these counties appear opened. The water drive in these pools is undoubtedly a great factor and should make for high recovery, as well as quick exhaustion and rapid decline. The large porosity of the Winkler pays suggests high recovery per acre.

---

* Vice president, Humphreys Corpn.

In the face of the low price at which Venezuela oil can be laid down on the Atlantic seaboard, one immediately is struck at the uneconomic production of West Texas oil at this time considering high transportation cost to Gulf or refinery. Low cost of production is partly offset by higher cost of treating.

A deep sand with, perhaps, higher grade oil will produce from part of these pools, but it does not bid fair to produce quantities comparable to that of the present sand; in addition, part of these pools may yield two high flush producing horizons in the Word, whereas only one appears in each pool.

L. G. Huntley,* Pittsburgh, Pa.—Personally I am an optimist on the quantity of oil in that part of the country. I cannot see how a region 250 miles long could be condemned as to the size or importance of the pools which might be found there. I am still afraid of that area.

W. T. Thom, Jr.,† Princeton, N. J.—Mr. Fohs rather devastated the area areally, but I am yet in the dark as to the possibilities of deeper sands.

F. J. Fohs.—To recapitulate, the pay horizons of West Texas of major consequence are apt to be one in the upper and another in the lower part of the Word formation—a formation about 800 ft. thick—and together with the underlying Leonard probably containing the chief oil source beds. It remains to be seen whether or not a producing formation will occur in the Leonard in some of the fields. Winkler may have another producing horizon in the lower half of the Word, the Yates and McCamey pools probably will not, as the Yates is probably producing from the lower Word while the McCamey has already been tested for 2000 ft. below the productive horizon without results. In the case of the Yates there is a chance, however, for the deep pay found at Big Lake pool. This was obtained there at a depth of 6200 ft. It is a high grade oil but is not looked upon as likely to have large gusher wells, nor is it sufficiently tested as yet to make predictions. Another producing horizon has had shows for wells up to 25 bbl. I refer to the basal part of the Gilliam formation, which overlies the Word from 1200 to 1700 ft., with the Vidrio formation intervening. The latter is not apt to yield oil in quantity as it is an exceedingly compact limestone.

J. E. Pogue,‡ New York, N. Y.—While discussing the reserves of West Texas, it is pertinent to point out that reserves like supply are a function of price and the volume of oil available at 60c per bbl. is doubtless much less than the total volume present in that territory.

S. S. Price,§ Tulsa, Okla.—I am inclined to think that Mr. Watson's figures are more or less sound, probably not too conservative.

J. M. Lovejoy,|| Tulsa, Okla.—To what extent is light Mid-Continent crude oil likely to be replaced by the sulfur-bearing oils of West Texas? What are the difficulties on refining the latter?

E. R. Lederer,¶ Fort Worth, Texas.—From the refining point of view I am satisfied that all the difficulties which are connected with the refining of West Texas crude will be overcome. In fact, they are now, to a great extent. It is just a question of applying the necessary talent to solve the problem. It is difficult for the small refiner

* Consulting Geological Engineer, Huntley & Huntley.

† Geologist, Department of Geology, Princeton University.

‡ Consulting Engineer.

§ Chief Geologist and Superintendent of Land Department, Dixie Oil Co.

|| Vice-president, Amerada Petroleum Corpn.

¶ Vice-president, Texas Pacific Coal & Oil Co.

to do this because special equipment and a great deal of research work are required, the distribution of the sulfur in West Texas crude being entirely different from that in Mexican crude. The sulfur appears in each in different chemical composition and has to be treated differently in each product. Gasoline can be produced from West Texas crude, good gasoline, meeting all specifications and requirements of performance, as well as though made from the best Mid-Continent crude, and the yields justify operating plants on this crude. Naturally the expenses in handling it are anywhere from 20 to 30 c. per bbl. more than on Mid-Continent crude. Unless we get more pipe-line outlets from West Texas into the Mid-Continent, a movement which already has been started by the Shell company, I do not see any danger of the West Texas crude market influencing the market in the central states.

E. R. Lilley,* New York, N. Y.—One thing that interests me is the implication that West Texas crude oil prices will have no effect upon the price structure of Oklahoma and Kansas simply because its crude oil will not be transported to those states. Both Oklahoma and Kansas are exporting substantial amounts of gasoline. They are also shipping southward to coastal refineries substantial amounts of crude oil. It is evident that if the Gulf refineries can secure West Texas crude oil at low prices they will not be in the market for crude oil from Oklahoma and Kansas. The competition between the two sections, while indirect, must be active and the effect of prices of West Texas crude oil upon those of Oklahoma allowed for.

I do not know what differentiation can be made because of the differences in the refining values of the oils of the two areas, but it is certain that the prices of the high quality oils of Oklahoma and Kansas can not be raised indefinitely if the prices of crude oils from West Texas are being lowered. It is true that the latter are primarily of fuel grade, but as their gasoline content can be materially increased by cracking, their availability as sources of gasoline is substantial.

The question as to whether we have 1,000,000,000 or 3,000,000,000 bbl. of oil in West Texas is not important to us at this time. It is sufficient to know when we are discussing the conditions for the next three or four years that we have a new and tremendous reserve of oil. We must realize that this large quantity of oil is to be secured from the type of pool which gives up its oil most easily, and that control of flush production is naturally most difficult. To further complicate the situation, the landownership in at least three of the major pools is so widely distributed that the difficulty of developing any method of unified control or action is a very serious one.

R. S. Knappen,† Tulsa, Okla.—I hesitate to disagree with the speakers who have discussed the small production coming out of West Texas. As I have looked over this paper, however, I am inclined to think Mr. Watson has been conservative in most of his estimates. There are considerable areas in West Texas which have not been tested. One has only to consider how close we came to missing the Hendricks pool. If that had been three locations west, we quite likely would not have the Hendricks pool at the present time. Some of the others have been found by almost as narrow a margin. Had the Big Lake discovery well been one location away, we would not have it. Is it not quite possible, therefore, that some others have been missed? As I think over the map, it seems to me there are large areas in Crane and Ward counties and considerable areas in Pecos County which have not been tested. I should rather like to believe in 1,000,000,000 bbl. for the West Texas reserve, but I am more inclined to believe that it will be closer to 3,000,000,000 bbl. before we get through.

* Associate Professor of Geology, New York University.

† Gypsy Oil Co.

The Loss Ratio Method of Extrapolating Oil Well Decline Curves

By Roswell H. Johnson* and A. L. Bollens,† Pittsburgh, Pa.

(New York Meeting, February, 1928)

The appraisal of oil wells, now that we have the age-size method of making composite decline curves, and the present worth of successive time units method of valuation, has its greatest remaining uncertainty in the difficulty of extending into the future the price curve and the composite production curve. The point of attack in this paper is the carrying on (or extrapolation) of the production curve.

Led by the valuable discovery of Lewis and Beal that the decline curve is nearer the hyperbolic class, $y = (x + a)^{-n}$, than any other form, the current practice is the graphic method. The data are plotted on logarithmic paper and shifted with successive trials until the line becomes straight. This straight line can then be extended into the future. The method was a great help during the period when, for tax purposes, there was need for a quick method even though the errors were large. Now that we seek greater validity in our methods we find the following faults with the current method.

1. Where the shift is great (it exceeds 10 in some cases) the scale cannot be read with the necessary precision so that the resulting data would give a very irregular and inaccurate curve.

2. Where the curve cannot be straightened on logarithmic paper because of sigmoid shape the method has a serious systematic error. We believe the sigmoid curves to be more common than usually supposed, indeed when one considers the number of variable causative factors this is to be expected.

We have therefore been seeking a method that is free from these difficulties and yet not so laborious as fitting a curve to the data and the calculation from the formula which, since it involves looking up logarithms, is unduly time-consuming. The method here described has been developed on the basis suggested by Earl Oliver, that the amount of oil produced per month or year for each reduction of production of a barrel of oil per day could be plotted to advantage. A step forward was made by Earl Carpenter in this laboratory, and some of the

* Professor, Oil and Gas Production, University of Pittsburgh.
† Graduate Assistant, University of Pittsburgh.

examples shown in this paper have been worked out by A. L. Bollens, who is now engaged in further application of this method.

Consider a well which declines on a curve making a straight line on logarithmic paper and of the formula $y = x^{-n}$. Instead of plotting on logarithmic paper we set up the following table:

Year	Production in Bbl., y	First Difference in Bbl. Yield per Unit of Time Δy	Ratio $r = y/\Delta y$ r	First Difference of r, Δr
1	1000			
2	500	500	1	
3	333	167	2	1
4	250	83	3	1
5	200	50	4	1
6	167	33	5	1

Since constancy is reached in the fourth column it is obvious that the r for the seventh year will be equal to that of the sixth year plus one or it equals six. Then, to find the yield for the seventh year, multiply the yield of the sixth year by the loss ratio of the seventh year divided by the loss ratio for that year plus one. This gives 167 times $6/7$, equals 143. In like manner the yields for successive years can be worked out as far into the future as needed. The factor, r over 1 plus r, can be obtained from a special table (Table 1) so that the operation can be reduced to one multiplication.

Let us consider next the more common case where the origin must be shifted in order to straighten the line on logarithmic paper. This requires considerable trial and rejection before the best shift is obtained. But with Table 1 we find that practical constancy will be obtained from about the fourth year on, so that this method is still available.

The advantage of this method is marked with a curve having a shift as great as 10 or more, because the logarithmic paper cannot be read properly.

Let us suppose that the rate changes still more slowly, the difficulty becomes greater with logarithmic paper, but with this method the difference between successive values of r becomes less and less. If the value of r becomes a constant then the curve is exponential.

Where Logarithmic Extrapolation Fails

The type of curve where the logarithmic extrapolation utterly fails is that which is sigmoid when plotted on logarithmic paper and made as straight as possible. It is clear that such a curve is not of the hyperbola class. We have too many conditions working together, such as one would expect in an oil reservoir, so that the true curve is probably a

polynomial such as $y = a + bx + cx^2$, or even $y = a + bx + cx^2 + dx^3$. However, the new method may still handle it:

Year	Production, in Bbl., y	Δy	r	Δr_1	Δr_2	Δr_3
1	15,000					
2	7,611	7,389	1.03			
3	4,977	2,634	1.89	−0.86		
4	3,677.5	1,299.5	2.83	−0.94	−0.08	
5	2,921	756.5	3.86	−1.03	−0.09	−0.01
6	2,433	488	4.99	−1.13	−0.10	−0.01
7	2,096	337	6.23	−1.24	−0.11	−0.01
8	1,852	244	7.59	−1.36	−0.12	−0.01
9	1,668	184	9.08	−1.49	−0.13	−0.01
10	1,525.5	142.5	10.71	−1.63	−0.14	−0.01

In the example given above the loss ratio for successive years is built up from the differences and the results of the previous years, working across the table from right to left. If the value of r for the eleventh year is desired start at the right and add 0.01 to 0.14 which gives 0.15. Add this to the first difference 1.63, which will give 1.78. This added to the r for the year, 10 or 10.78, equals 12.48, which is the value of the loss ratio for the eleventh year. The yield for that year is worked out as shown above in a simpler case. The formula for any year's production is

$$y_n = y_{n-1}\left(\frac{r_n}{r_n + 1}\right)$$

Applications When Loss Ratio's are Irregular

Still another service may be had from this method if the loss ratios for the years for which there are data, are found to vary irregularly. The vulues of r can be graphed on squared paper and their trend extended into the future with a greater accuracy than the logarithmic extrapolation of the original data.

An example of this method of treatment is shown by using the production record of a well in N. W. ¼, Sec. 23, T. 24, R. 9, Osage County, Oklahoma:

Year	y	Δy	r	Δr	Average, Δr	r from Average	r from Graph
1	5700						
2	3500	2200	1.51				
3	2300	1200	1.92	0.33			
4	1700	600	2.84	0.92			
5	1325	375	3.54	0.70			
6	1050	375	3.82	0.28			
7					0.56	4.38	4.4
8						4.94	5.0
9						5.50	5.6

The successive differences of the loss ratio will not reach constancy but the first difference is fairly close to constancy. By plotting the value of the loss ratio against the corresponding year of the well's life the graph can be extended into the future by means of a straight line extrapolation and the desired values of r read from the graph. (Fig. 1.) Also the arithmetic average of the first difference of r can be taken as a constant and added to the r for each year giving very nearly the same result as that obtained by the graphic method. On the well cited both

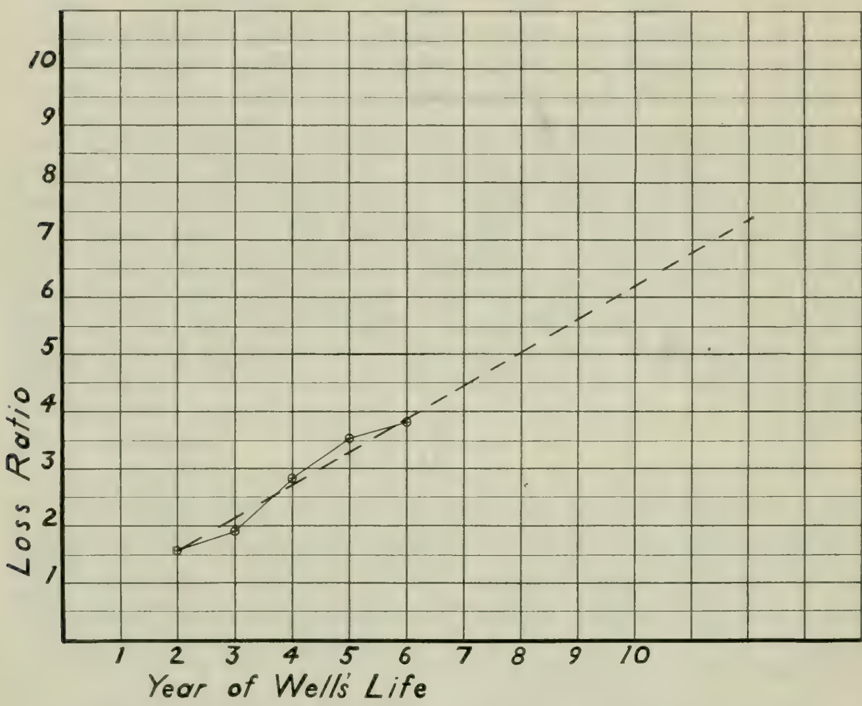


Fig. 1.—Extrapolation of loss ratio.

methods were used and the results checked very closely with the best possible logarithmic extrapolation that could be done. The operation was no more laborious and the results were free from errors in reading curves and errors due to the personal equation. The junior author is at present working on those curves in which the first difference has a change in rate, in order to find a method of application. Such instances are not numerous but at some time or in a particular field may be common enough to be important, and a good method of handling them will be needed.

Conclusion

We believe that the extrapolation of loss ratio on a straight line is much safer than logarithmic extrapolation because we can eliminate the effect of faulty grid and errors due to difficulty in reading the very fine part of the scale. No superiority is claimed for the new method where no shift of origin is necessary or where the shift is very small, but where the shift is as large as 10 the new method is indicated as the proper recourse, as the only alternative, that of working out the formula itself and the calculation of the extrapolated values takes much time and an amount and sort of calculation shunned by most appraisers. We believe these types in which the new method is indicated include more than one-half of our curves.

TABLE 1.—*Table for Calculating Production of Any Year.*

The loss ratio is the production of a time unit divided by the loss for previous time unit, also preceding loss ratio plus difference between successive time units.

Loss, Ratio, r	Percentage of Yield of Preceding Time Unit, $\frac{r}{r+1}$	Loss, Ratio, r	Percentage of Yield of Preceding Time Unit, $\frac{r}{r+1}$	Loss, Ratio, r	Percentage of Yield of Preceding Time Unit, $\frac{r}{r+1}$	Loss, Ratio, r	Percentage of Yield of Preceding Time Unit, $\frac{r}{r+1}$
0.11	0.099	0.81	0.448	1.51	0.602	2.21	0.689
.12	.107	.82	.451	1.52	.603	2.22	.689
.13	.115	.83	.454	1.53	.605	2.23	.690
.14	.123	.84	.457	1.54	.606	2.24	.691
.15	.130	.85	.459	1.55	.608	2.25	.692
.16	.137	.86	.462	1.56	.609	2.26	.693
.17	.145	.87	.465	1.57	.611	2.27	.694
.18	.153	.88	.468	1.58	.612	2.28	.695
.19	.160	.89	.471	1.59	.614	2.29	.696
.20	.167	.90	.474	1.60	.615	2.30	.697
.21	.174	.91	.476	1.61	.617	2.31	.698
.22	.180	.92	.479	1.62	.618	2.32	.699
.23	.187	.93	.482	1.63	.620	2.33	.700
.24	.194	.94	.485	1.64	.621	2.34	.701
.25	.200	.95	.487	1.65	.623	2.35	.701
.26	.206	.96	.490	1.66	.624	2.36	.702
.27	.213	.97	.492	1.67	.625	2.37	.703
.28	.219	.98	.495	1.68	.627	2.38	.704
.29	.225	.99	.497	1.69	.628	2.39	.705
.30	.231	1.00	.500	1.70	.630	2.40	.706
.31	.237	1.01	.502	1.71	.631	2.41	.707
.32	.242	1.02	.505	1.72	.632	2.42	.708
.33	.248	1.03	.507	1.73	.634	2.43	.708
.34	.254	1.04	.510	1.74	.635	2.44	.709
.35	.259	1.05	.512	1.75	.636	2.45	.710
.36	.265	1.05	.515	1.76	.638	2.46	.711
.37	.270	1.07	.517	1.77	.639	2.47	.712
.38	.275	1.08	.519	1.78	.640	2.48	.713
.39	.281	1.09	.522	1.79	.642	2.49	.713
.40	.286	1.10	.524	1.80	.643	2.50	.714
.41	.291	1.11	.526	1.81	.644	2.51	.715
.42	.296	1.12	.528	1.82	.645	2.52	.716
.43	.301	1.13	.531	1.83	.647	2.53	.717
.44	.306	1.14	.533	1.84	.648	2.54	.718
.45	.310	1.15	.535	1.85	.649	2.55	.718
.46	.315	1.16	.537	1.86	.650	2.56	.719
.47	.320	1.17	.539	1.87	.652	2.57	.720
.48	.324	1.18	.541	1.88	.653	2.58	.721
.49	.329	1.19	.543	1.89	.654	2.59	.721
.50	.333	1.20	.545	1.90	.655	2.60	.722
.51	.338	1.21	.548	1.91	.656	2.61	.723
.52	.342	1.22	.550	1.92	.658	2.62	.724
.53	.346	1.23	.552	1.93	.659	2.63	.725
.54	.351	1.24	.554	1.94	.660	2.64	.725
.55	.355	1.25	.556	1.95	.661	2.65	.726
.56	.359	1.26	.558	1.96	.662	2.66	.727
.57	.363	1.27	.559	1.97	.663	2.67	.728
.58	.367	1.28	.561	1.98	.664	2.68	.728
.59	.371	1.29	.563	1.99	.666	2.69	.729
.60	.375	1.30	.565	2.00	.667	2.70	.730
.61	.379	1.31	.567	2.01	.668	2.71	.730
.62	.383	1.32	.569	2.02	.669	2.72	.731
.63	.387	1.33	.571	2.03	.670	2.73	.732
.64	.390	1.34	.573	2.04	.671	2.74	.733
.65	.394	1.35	.574	2.05	.672	2.75	.733
.66	.398	1.36	.576	2.06	.673	2.76	.734
.67	.401	1.37	.578	2.07	.674	2.77	.735
.68	.405	1.38	.580	2.08	.675	2.78	.735
.69	.408	1.39	.582	2.09	.676	2.79	.736
.70	.412	1.40	.583	2.10	.677	2.80	.737
.71	.415	1.41	.585	2.11	.678	2.81	.738
.72	.419	1.42	.587	2.12	.679	2.82	.738
.73	.422	1.43	.588	2.13	.681	2.83	.739
.74	.425	1.44	.590	2.14	.682	2.84	.740
.75	.429	1.45	.592	2.15	.683	2.85	.740
.76	.432	1.46	.593	2.16	.684	2.86	.741
.77	.435	1.47	.595	2.17	.685	2.87	.742
.78	.438	1.48	.597	2.18	.686	2.88	.742
.79	.441	1.49	.598	2.19	.687	2.89	.743
.80	.444	1.50	.600	2.20	.688	2.90	.744

TABLE 1.—*Table for Calculating Production of Any Year.*—(*Continued*)

Loss, Ratio, r	Percentage of Yield of Preceding Time Unit, $\frac{r}{r+1}$	Loss, Ratio, r	Percentage of Yield of Preceding Time Unit, $\frac{r}{r+1}$	Loss, Ratio, r	Percentage of Yield of Preceding Time Unit, $\frac{r}{r+1}$	Loss, Ratio, r	Percentage of Yield of Preceding Time Unit, $\frac{r}{r+1}$
2.91	0.744	3.65	0.785	4.39	0.814	5.13	0.837
2.92	.745	3.66	.785	4.40	.815	5.14	.837
2.93	.746	3.67	.786	4.41	.815	5.15	.837
2.94	.746	3.68	.786	4.41	.815	5.16	.838
2.95	.747	3.69	.787	4.42	.816	5.17	.838
2.96	.747	3.70	.787	4.43	.816	5.18	.838
2.97	.748	3.71	.788	4.45	.817	5.19	.838
2.98	.749	3.72	.788	4.46	.817	5.20	.839
2.99	.749	3.73	.788	4.47	.817	5.21	.839
3.00	.750	3.74	.789	4.48	.818	5.22	.839
3.01	.751	3.75	.789	4.49	.818	5.23	.839
3.02	.751	3.76	.790	4.50	.818	5.24	.840
3.03	.752	3.77	.790	4.51	.819	5.25	.840
3.04	.752	3.78	.791	4.52	.819	5.26	.840
3.05	.753	3.79	.791	4.53	.819	5.27	.841
3.06	.754	3.80	.792	4.54	.819	5.28	.841
3.07	.754	3.81	.792	4.55	.820	5.29	.841
3.08	.755	3.82	.793	4.56	.820	5.30	.841
3.09	.756	3.83	.793	4.57	.820	5.31	.842
3.10	.756	3.84	.793	4.58	.821	5.72	.842
3.11	.757	3.85	.794	4.59	.821	5.33	.842
3.12	.757	3.86	.794	4.60	.821	5.34	.842
3.13	.758	3.87	.795	4.61	0.822	5.35	.843
3.14	.758	3.88	.795	4.62	.822	5.36	.843
3.15	.759	3.89	.796	4.63	.822	3.37	.843
3.16	.760	3.90	.796	4.64	.823	5.38	.843
3.17	.760	3.91	.796	4.65	.823	5.39	.844
3.18	.761	3.92	.797	4.66	.823	5.40	.844
3.19	.761	3.93	.797	4.67	.824	5.41	.844
3.20	.762	3.94	.798	4.68	.824	5.42	.844
3.21	.762	3.95	.798	4.69	.824	5.43	.844
3.22	.763	3.96	.798	4.70	.825	5.44	.845
3.23	.764	3.97	.799	4.71	.825	5.45	.845
3.24	.764	3.98	.799	4.72	.825	5.46	.845
3.25	.765	3.99	.800	4.73	.825	5.47	.845
3.26	.765	4.00	.800	4.74	.826	5.48	.846
3.27	.766	4.01	.800	4.75	.826	5.49	.846
3.28	.766	4.02	.801	4.76	.826	5.50	.846
3.29	.767	4.03	.801	4.77	.826	5.51	.846
3.30	.767	4.04	.802	4.78	.827	5.52	.847
3.31	.768	4.05	.802	4.79	.827	5.53	.847
3.32	.769	4.06	.802	4.80	.828	5.54	.847
3.33	.769	4.07	.803	4.81	.828	5.55	.847
3.34	.770	4.08	.803	4.82	.828	5.56	.848
3.35	.770	4.09	.804	4.83	.828	5.57	.848
3.36	.771	4.10	.804	4.84	.829	5.58	.848
3.37	.771	4.11	.804	4.85	.829	5.59	.848
3.38	.772	4.12	.805	4.86	.829	5.60	.848
3.39	.772	4.13	.805	4.87	.830	5.61	.849
3.40	.773	4.14	.805	4.88	.830	5.62	.849
3.41	.773	4.15	.806	4.89	.830	5.63	.849
3.42	.774	4.16	.806	4.90	.831	5.64	.849
3.43	.774	4.17	.807	4.91	.831	5.65	.850
3.44	.775	4.18	.807	4.92	.831	5.66	.850
3.45	.775	4.19	.807	4.93	.831	5.67	.850
3.46	.776	4.20	.808	4.94	.832	5.68	.850
3.47	.776	4.21	.808	4.95	.832	5.69	.851
3.48	.777	4.22	.808	4.96	.832	5.70	.851
3.49	.777	4.23	.809	4.97	.832	5.71	.851
3.50	.778	4.24	.809	4.98	.833	5.72	.851
3.51	.778	4.25	.810	4.99	.833	5.73	.851
3.52	.779	4.26	.810	5.00	.833	5.74	.852
3.53	.779	4.27	.810	5.01	.834	5.75	.852
3.54	.780	4.27	.811	5.02	.834	5.76	.852
3.55	.780	4.27	.811	5.03	.834	5.77	.852
3.56	.781	4.30	.811	5.04	.834	5.78	.853
3.57	.781	4.31	.812	5.05	.835	5.79	.853
3.58	.782	4.32	.812	5.06	.835	5.80	.853
3.59	.782	4.33	.812	5.07	.835	5.81	.853
3.60	.783	4.34	.813	5.08	.836	5.82	.853
3.61	.783	4.35	.813	5.09	.836	5.83	.854
3.62	.784	4.36	.813	5.10	.836	5.84	.854
3.63	.784	4.37	.814	5.11	.836	5.85	.854
3.64	.784	4.38	.814	5.12	.837	5.86	.854

TABLE 1.—*Table for Calculating Production of Any Year.*—(*Continued*)

Loss, Ratio, r	Percentage of Yield of Preceding Time Unit, $\frac{r}{r+1}$	Loss, Ratio, r	Percentage of Yield of Preceding Time Unit, $\frac{r}{r+1}$	Loss, Ratio, r	Percentage of Yield of Preceding Time Unit, $\frac{r}{r+1}$	Loss, Ratio, r	Percentage of Yield of Preceding Time Unit, $\frac{r}{r+1}$
5.87	0.854	7.65	0.884	11.2	0.918	43	0.9773
5.88	.855	7.70	.885	11.3	.919	44	.9778
5.89	.855	7.75	.886	11.4	.919	45	.9783
5.90	.855	7.80	.886	11.5	.920	46	.9787
5.91	.855	7.85	.887	11.6	.921	47	.9792
5.92	.855	7.90	.888	11.7	.921	48	.9796
5.93	.856	7.95	.889	11.8	.922	49	.9800
5.94	.856	8.00	.889	11.9	.922	50	.9804
5.95	.856	8.05	.890	12.0	.9231	51	.9808
5.96	.856	8.10	.890	12.5	.926	52	.9811
5.97	.857	8.15	.891	13.0	.9286	53	.9815
5.98	.857	8.20	.891	13.5	.931	54	.9818
5.99	.857	8.25	.892	14.0	.9333	55	.9821
6.00	.857	8.30	.892	14.5	.935	56	.9825
6.01	.857	8.35	.893	15.0	.9375	57	.9828
6.02	.858	8.40	.894	15.5	.939	58	.9831
6.03	.858	8.50	.895	16.0	.9412	59	.9833
6.04	.858	8.55	.895	16.5	.943	60	.9836
6.05	.858	8.60	.896	17.0	.9444	61	.9839
6.06	.858	8.65	.896	17.5	.946	62	.9841
6.07	.859	8.70	.897	18.0	.9474	63	.9844
6.08	.859	8.75	.897	18.5	.949	64	.9846
6.09	.859	8.80	.898	19.0	.9500	65	.9848
6.10	.859	8.85	.898	19.5	.951	66	.9851
6.11	.859	8.90	.899	20.0	.9524	67	.9853
6.12	.860	8.95	.899	20.5	.953	68	.9855
6.13	.860	9.00	.9000	21.0	.9545	69	.9857
6.14	.860	9.05	.9005	21.5	.956	70	.9859
6.15	.860	9.10	.901	22.0	.9565	71	.9861
6.20	.861	9.15	.9015	22.5	.957	72	.9863
6.25	.862	9.20	.902	23.0	.9583	73	.9865
6.30	.863	9.25	.9024	23.5	.959	74	.9867
6.35	.864	9.30	.903	24.0	.9600	75	.9868
6.40	.865	9.35	.9034	24.5	.961	76	.9870
6.45	.866	9.40	.904	25.0	.9615	77	.9872
6.50	.867	9.45	.9043	25.5	.962	78	.9873
6.55	.868	9.50	.905	26.0	.9630	79	.9875
6.60	.868	9.55	.9052	26.5	.964	80	.9877
6.65	.869	9.60	.906	27.0	.9643	81	.9878
6.70	.870	9.65	.9061	27.5	.965	82	.9880
6.75	.871	9.70	.907	28.0	.9655	83	.9881
6.80	.872	9.75	.9070	28.5	.966	84	.9882
6.85	.873	9.80	.907	29.0	.9667	85	.9884
6.90	.873	9.85	.9078	29.5	.967	86	.9885
6.95	.874	9.90	.908	30	.9677	87	.9886
7.00	.875	10.00	.909	31	.9688	88	.9888
7.05	.876	10.1	.910	32	.9697	89	.9889
7.10	.877	10.2	.911	33	.9706	90	.9890
7.15	.877	10.3	.912	34	.9714	91	.9891
7.20	.878	10.4	.912	35	.9722	92	.9892
7.25	.879	10.5	.913	36	.9730	93	.9894
7.30	.880	10.6	.914	37	.9737	94	.9895
7.35	.880	10.7	.915	38	.9744	95	.9896
7.40	.881	10.8	.915	39	.9750	96	.9897
7.45	.882	10.9	.916	40	.9756	97	.9898
7.50	.882	11.0	.9167	41	.9762	98	.9899
7.55	.883	11.1	.917	42	.9767	99	.9900
7.60	.884						

Cooperative Development of Oil Pools

By O. E. Kiessling,* Washington, D. C.

(New York Meeting, February, 1928)

[Summary prepared by author for presentation at meeting. Complete paper is available as A. I. M. E. *Technical Publication* No. 28; for extensive abstract see *Mining and Metallurgy* (Nov., 1927) 460–462.]

Viewed from the standpoint of an economist, the task which faces the petroleum producing industry is one of intelligent adjustment so that technology can perform the job of efficient exploitation, while at the same time the interests of producers and consumers remain adequately protected.

The crux in the task of making this adjustment lies in the difficulty of arranging the instrumentalities of production to accord with the physical characteristics of oil. For example, oil is exploited under a competitive economic system based on private ownership and contract, with the hope that profits will attract capital and enterprise, and with competition supposedly acting as the regulative factor. Whether such a scheme of industrial organization works is partially dependent upon the ability of the producer to withold or produce his commodity as he sees fit, in accordance with market demand. But in the oil industry, the enterpriser does not have complete control over the expansion and contraction of production, for, because of the decisions of the courts that ownership in oil depends upon its possession, desire for immediate output becomes the controlling force in production. Consequently, the theoretical commands and restraints of free enterprise are not operative because there is no security of property, and the result is loss due to the following economic maladjustments:

(1) Production not completely responsive to price control.

(2) Production at excessive cost.

(3) Loss of oil, a highly exhaustible natural resource.

If economic maladjustments are to be eliminated, there should be a change in the organization of production so as to provide efficient exploitation of the oil and at the same time to insure individual property interests. The latter is necessary if economic considerations are to become primary factors in regulating production. To attain these ends, the entire pool should be developed as one big engineering project and some scheme

* Mineral Economist.

provided whereby the individual is secure in the possession of what is ordinarily thought of as property.

The degree to which such a plan will recommend itself to producers as a practical proposition will depend primarily upon the extent to which their profits will be increased. As regards the public, the primary consideration is a plentiful supply of oil delivered at a reasonable price and produced at lowest possible cost. Cooperative development as a method of unit operation fulfills both of these expectations.

Developing the pool as one engineering enterprise, however, demands a plan for satisfactorily reconciling the equities of the various owners. The plans for allocation of royalties in the 12 fields studied, where some sort of cooperative procedure is followed, are regarded as inadequate, chiefly because they do not account for the potentiality of a given property to produce oil. The details in these various schemes have been governed by the willingness of owners to accept them, rather than by the equitableness of a particular arrangement. Yet, for the solution of the problem, it is necessary to work out a scheme for putting each owner on an equitable basis so that he will receive the amount of royalty to which he is entitled because of the nature of his property and the relationship it bears to the rest of the pool. And a device which minimizes the influences of guess and chance, which lays down rules for procedure, whereby two intelligent men starting with the same facts will arrive at essentially the same results, is necessary.

Assuming that the owners in a pool have formed a corporation, the procedure for an equitable allocation is outlined as follows: Royalties shall be alloted to the various individuals within the group on two bases:

(1) Distribution of one-third in proportion to holdings of acreage.

(2) Distribution of two-thirds in proportion to potential recoverable content of gas and oil as measured by the estimated volume of oil and gas sand within the property.

With regard to the second basis for distribution of royalties, the degree to which the volume of oil is recoverable can be estimated with considerable precision from the known laws of gas expansion; from experimental determination of the porosity, permeability and saturation of the cores of pay sand; and from tests of the fluidity of the contained oil, and there are other various checks which might be employed. With regard to the suggested ratio for allocation, the writer does not consider any of his suggestions inflexible, and realizes that the mutual agreement of cooperators will ultimately be the determining factor in deciding with precision such things as amounts of royalty, proportions of division, and other similar questions.

A test period, two to four years being suggested, is necessary before final allocation could be made, during which royalties are paid in part, a certain proportion being held in escrow pending final settlement. The

final allocation becomes the basis for the distribution of stock and accumulated royalty, the rate of the latter being determined by bargaining between corporations—the owners and the operator—and the introduction of "sliding scale" clauses into leases is contemplated.

Only a few of the many reasons why the plan is equitable can be given in this summary:

(1) It establishes the concept of property in oil underground, and sets up a mechanism for the protection of that property.

(2) It insures each individual the returns from his property.

(3) It increases the profits which both the royalty owners and operators receive.

The suggested plan is no more than a definite proposal outlining a procedure, and the very nature of the scheme demands cooperation between the owners, operators, and the state for the settling of details. This feature introduces an element of flexibility so necessary when variable conditions are dealt with. In regard to the function of the government in this arrangement, the state legislature provides the machinery which enables cooperation between owners of oil properties in the same manner as the cooperation of individuals is made possible in the organization of irrigation projects. This mechanism should not be regulative, but cooperative—with the state government as one of the cooperators. Development would be entirely voluntary and there would be merely a drawing of the lines within which private initiative and enterprise might have the greatest possible scope. Such cooperation on the part of the state would obviate the need for the present laws regulating petroleum production.

The authority for the state government to participate in this cooperation is found in the "general welfare" doctrine of the police power. The case for the constitutionality of the participation is presented along the following lines:

(1) The public welfare is intimately concerned in preventing waste by stopping losses of oil and in eliminating economic maladjustments.

(2) There is a need for state participation if individual property rights in oil are to be safeguarded.

Regulating oil production is regarded as outside of the authority of the Federal government, except in case of an impending national peril, or unless the constitution were amended for this express purpose.

Finally, the proposal does not carry as a consequence the destruction of competition with respect to the price of petroleum products, for hundreds of pools would still compete in the sale of oil. In fact, when economic considerations are the primary factors governing production, prices are likely to be more stable and lower in the long run, perhaps not lower than they have been, but lower than they would be if the supply were not augmented through the more efficient methods of exploitation.

DISCUSSION

F. O. Martin,* Los Angeles, Cal. (written discussion).—I do not believe that landowners should receive parts of their royalties in proportion to potential recoverable content of gas and oil as measured by the estimated volume of oil and gas sand within a property, but the royalties should be based solely on the respective acreage within a structure owned by different owners. Nearly all landowners bought their lands originally for agricultural or residence purposes and they have no legitimate reason to demand excessive profits, because through no efforts or expense on their part such lands have become valuable. I believe that too much is being said and written about the profits made by legitimate oil companies without taking into consideration the immense costs and risks assumed by them and too little or nothing is said about the lucky landowners who make all profits without spending or risking one cent.

The man who never loses in the oil game is the landowner. He receives immense profits in bonuses and royalties for merely leasing the land and often refuses to sell the land outright at any reasonable price. The landowner usually has done nothing at all towards proving any prospective oil value thereof. The oil companies spend great sums of money for scientific work in discovering and proving new oil fields and long before they receive any return on money expended, the landowners have received their bonuses and royalties.

I am not of course referring to lands owned by companies which are actually in the oil business. Such companies, if farseeing and having the resources to do so, have bought and buy lands for future development and production. I may instance the holdings of the Union Oil Co. of California in the Santa Maria and Lompoc districts and the fact that the Standard Oil Co. (California) bought all of sections 16 and 36 (school land sections) from Coalinga to Maricopa many years ago. This practice, however, becomes more difficult from year to year and the oil companies are forced to lease lands.

Goverment regulation of oil development would be easier if the subsurface right had always been possessed by the government as they have been for about 10 years. By withholding certain areas from leases at times of a threatening oversupply, the oil production might be made more stable. However, under the present conditions I do not believe that any law enacted by Congress or regulation by any federal department can satisfy the different problems in different states.

Any remedies to control the oil supply in the United States should originate with the oil companies themselves as they know more about it than any outsiders. Conservation measures should originate in the respective states because state legislatures are more responsive to the needs of their constituents and know more about them.

Referring to the cooperative development of oil pools or unit operation along the same lines as in irrigation districts, I would point out a great difference between the two schemes. In an irrigation district the landowners have to pay all the expenses of development according to the areas owned by them, while the owners of prospective oil lands very seldom spend any money themselves for development, but rather expect to have an oil company pay for the privilege to spend a large amount of money to develop oil production on the land, and after this is done, pay royalties to the landowners in the pool. Besides, it mostly happens, as the author points out, that even before oil development is thought of, different oil companies and leasing concerns, individuals or organizations, have already leased said lands and often with different lease conditions. It would be difficult to reconcile the different equities. I imagine that such equities could be reconciled if only bona fide oil companies were concerned

* Geologist, Union Oil Co. of California.

in them, but other lease holders with practically nothing to lose and all to gain are more difficult to deal with. Court actions will become necessary.

It is the practice of some large oil companies prior to drilling a new location to bring under their control by leasing or otherwise as much land on a structure as possible for their own protection or to share costs of development with other oil companies. The drawback to all reasonable and judicious development of oil production has always been and is now some avaricious landowner or his agent.

Since different cities have different building regulations, some cities limiting the height of buildings, thereby spreading out the business district and avoiding congestion, and also divide the increasing value of real estate over a large district among many landowners; would it not be possible to regulate by law the spacing of wells depending on the conditions existing in any particular structure and compensate the owners of land according to the areas held by them in said structure?

Chapter XVII. Export Trade

The Economic Outlook for Exports of Petroleum Products

By John H. Nelson,* Washington, D. C.

(New York Meeting, February, 1928)

An outline survey of the economic outlook for the United States export trade in petroleum products resolves itself broadly into two general divisions; first, a consideration of our present position in this trade, and second, a discussion of the visible factors which promise to affect appreciable changes in the immediate future in that trade. The

United States Petroleum Exports of Major Petroleum Products 1925, 1926 and 1927

Gasoline, Naphtha, and Other Light Products

	1925	1926	1927*
Quantity (gal.)	1,286,787,796	1,784,154,802	1,851,494,190
Value	$197,491,588	$263,199,938	$214,721,652

Illuminating Oil, Kerosene

	1925	1926	1927*
Quantity (gal.)	885,136,041	924,680,979	827,162,280
Value	$84,699,724	$100,352,877	$80,358,082

Gas and Fuel Oil

	1925	1926	1927
Quantity (gal.)	1,365,358,988	1,449,688,394	1,815,130,464
Value	$49,040,024	$45,354,108	$50,343,031

Lubricating Oil

	1925	1926	1927
Quantity (gal.)	402,572,584	388,767,055	403,369,512
Value	$90,596,671	$86,414,621	$88,926,815

* All 1927 twelve months' figures estimates based on actual exports for the first eleven months of 1927.

* Petroleum Section, Minerals Division, Bureau of Foreign and Domestic Commerce.

statistical analysis and mathematical calculations which usually accompany a study of this subject are omitted from this paper. The factors abroad which promise to have the greatest effect on the future trend of our petroleum exports do not permit at this time of such mathematical treatment with an appreciable degree of accuracy.

Exports from the United States

Petroleum exports as a group have ranked consistently second among all major classifications of United States exports for many years, and first of all manufactured or processed commodities.

Based on the eleven months' figures the total value of all petroleum exports for the calendar year 1927 will be $491,635,681, in comparison with $554,533,629 for the year 1926. Quantitatively, for the same periods our total exports of crude and refined products were 5,206,465,247 gal. and 5,451,896,159 gal., respectively. An increase of approximately 4.7 per cent. in total quantity exported was accompanied by a decreased valuation of approximately 11 per cent., which was to be expected in view of the generally decreasing values of all petroleum products.

Geographical Distribution of United States Petroleum Exports for the Year 1927*

	Gasoline, Naphtha, and Other Light Products, Per Cent. of Total	Illuminating Oil (Kerosene), Per Cent. of Total
Europe	68	46.6
American Continent†	15.6	8.1
Far East	10.6	35.5
Africa	4.	5.2
Other Countries	1.8	4.6
	100.0	100.0
	Gas and Fuel Oil‡	Lubricating Oil‡
Europe	22.4	66.
American Continent†	57.9	12.6
Far East	16.2	14.9
Africa	1	2.4
Other Countries	3.4	4.1
	100.0	100.0

* Based on eleven months' actual exports, does not include fuel or bunker oil laden on vessels engaged in the foreign trade, which aggregated approximately 50,000,000 bbl. for the year 1927.

† Includes all countries of North and South America, with the exception of the United States.

‡ Does not include 594,434 bbl. of black oils exported but not classified as to countries of destination.

Distribution of U. S. Petroleum Exports

Of the total of refined products of petroleum exported (includes gasoline, kerosene, gas and fuel oil, and lubricating oil) Europe received 47.3 per cent., or very close to one-half of our total exports. The remarkable differences between the percentages of our exports to Europe and all other geographical classifications, with the possible exception of the American continent, would tend to indicate at first glance a potential opportunity for the profitable development of petroleum consumption in those areas. However, a casual study of the economic status of those areas, taking into account population, standards of living, industrial status, highway development and other pertinent factors gives little prospect of any quantitative increased petroleum consumption of sufficient volume to effect radical changes in the trend of our petroleum exports for many years to come.

An important factor in our export trade is the tremendous capital investment abroad necessary to carry on this trade by American oil companies; an investment that distinguishes this export from practically all other major American exports. The exact figure of this investment is impossible to obtain, of course. Several of the largest American oil companies engaged in large-scale exporting have kindly furnished the author with estimates of the total amount of American capital devoted to foreign oil-marketing operations. These estimates range from one billion one hundred million dollars to one billion five hundred million dollars, and all are stated to be conservative rather than excessive estimates. Proof of a conservative nature of these estimates is indicated in the fact that reports from only five of the larger exporting companies in themselves total six hundred and ninety-eight million three hundred thousand dollars. The natural reluctance with which the individual oil companies furnish figures on this subject prevents a further request for a detailed analysis as to the specific amounts invested in the different phases of the industry abroad, such as production, marketing, transportation, and others.

The author's request to the specific companies furnishing these figures emphasized the interest only in the amount of capital necessary to conduct our oil-export trade. Whether the replies were confined to this limit is exceedingly doubtful. For the purposes of this paper the total unqualified estimate is sufficient, since as a whole it is directly affected by the factors that affect the economic outlook for American export oil trade.

Tendency toward Legislative Control of the Oil Industry in Foreign Countries

The past few years have been marked by a progressively increasing nationalistic tendency to control on a world-wide scale and to regulate the

petroleum industry by legislative enactments. The two most common forms of such legislation are the establishment of monopolies for the sale and distribution of all oil products and that form of legislation nationalizing petroleum production. In a number of cases the two merge to such an extent that to all intents and effect they are one and the same thing. In certain British and Dutch possessions conditions similar to nationalization and monopolistic control exist by reason of general national policy rather than specific act. A brief and far from exhaustive summary of these factors is outlined in the following paragraphs.

Spain

By Royal Decree of June 28, Spain has been the latest country to attempt government control of the oil industry. On Oct. 20, 1927, an exclusive monopoly for the importation, storage, distribution and sale of all oil products in Spain was granted to a Banking Consortium made up of some thirty-seven of the most important banks in Spain. The oil properties in Spain of British, American and other nationals are to be expropriated and the owners reimbursed according to an established plan. The Spanish Royal Decree published on October 20 gives the Director General of the Stamp Tax full powers to take any action necessary to assure an adequate supply of oil until the company which has been awarded the monopoly is in normal operation. The Minister of Finance is authorized to seize immediately any or all organizations producing or distributing petroleum if he judges this to be in the public interest. When the Minister of Finance judges it necessary, he is to place before the Council of Ministers proposals for all or any seizures of property, indemnification for which is to be made later in accordance with Article 10 of the original monopoly of June 28. The Stamp Tax Director can impose fines up to 25,000 pesetas on any interest obstructing the execution of the above provisions. Criminal proceedings and higher fines may be inflicted by a majority vote of the cabinet.

The original decree of June 28 automatically prevents legal recourse to the courts for the determination of property values and provides a special commission for this purpose.

France

Reports from France advise that an alternative to a state petroleum monopoly has been proposed in the form of governmental regulation of imports by a system of licensing. A tariff differential is to be established in favor of crude-oil imports to rehabilitate and reëstablish a refining industry in France. The latter legislative proposal seems to have a reasonable expectation of becoming law within the near future, and April

1, 1928, has been set as the date on which possible new petroleum legislation shall become effective.

It will be recalled that April, 1927, was the original date set for the establishment of a French State Monopoly for the importation of all oil products into France, but that through a compromise agreement between the government and the promoters of this legislation a delay until Jan. 1, 1928, was accepted for the actual establishment of such a monopoly. Further legislation was, and is still, needed to cover the general regulations for the organization of the import monopoly, either by the state or through its concession to a company under state control. This date of January 1 is not imperative but depends on the results of investigations made by a committee of 44 members designated equally by the Chamber of Finance and Mines Committees. It is understood that a majority of this committee favor early enactment of monopoly legislation.

Several bills have been introduced into the French Chamber of Deputies during the past two years for the operation of a petroleum monopoly. Prominent among these was the Margaine Bill, which called for the formation of a company with a capital of 400 million francs, with half of the shares plus one to be subscribed by the State. Private refineries under this bill would operate only on concessions from the government and all installations, warehouse, tanks, tank cars and barges would be subject to requisitions for which an indemnity would be paid. In France the chief obstacle to a petroleum monopoly has been based on the difficulties encountered in securing the necessary operating capital and credits.

Italy

Italy has a State-subsidized oil company known as the Azienda Generale Italiana Petroli. The official statements made on the formation of this company deny all intention of monopolistic control. According to Italian sources it is supposed to "assist" private enterprise and exercise disciplinary control on the operations of foreign oil companies in Italy by selling oil at reduced prices. Its original capital of 200,000,000 lire has been spent twice since its formation in 1926 and operations continue largely by reason of grants from the national public treasury.

Russia

Russia, of course, represents a complete nationalization of petroleum production and monopolistic control of both domestic and foreign sales. According to Russian sources, 30 per cent. of her national income is from the oil industry. The demands of other branches of the Russian Government on this revenue have been such that funds for explorational work, maintenance and replacement of equipment in the oil industry

itself have suffered. More detailed discussions of Russia will be offered later.

Rumania

Rumania, by its mining law of 1921, nationalized its petroleum industry for the purpose of protecting itself from foreign exploitation of so vital a national resource. None but Rumanian citizens may hold title to oil properties and no thought of control of actual production or sales was expressed or implied. The elementary fact that the petroleum industry required tremendous amounts of capital for its continuous operation and that Rumania lacks such capital was ignored. From the standpoint of continuous production the Rumanian fields are among the oldest in the world. In 1926, production reached a new high figure for all time.

Poland

Poland prefers the Cartel system and on Dec. 10, 1927, established a new Petroleum Cartel to control oil production and sales. The old Polish Cartel for Oil did not function efficiently because, while prices were regulated by the Cartel, the actual sales were transacted by members and an abuse of this privilege destroyed all the benefits under the former organization. The new Cartel proposes to open sales and distribution offices to transact all business in the name of the Cartel itself.

Greece

The old provinces of Greece have had a kerosene monopoly for years. A number of rumors have recently discussed the early probability of a gasoline monopoly to raise funds for highway development projects.

Turkey

Turkey has, among other monopolies, one for petroleum, which effectively prohibits the functioning of the natural laws of supply and demand. While this monopoly cannot be said to function efficiently, much of its apparent success is due to the fact that the distribution facilities and personnel of one of the large American oil companies occupies an important position in directing the business, utilizing Russian oil almost exclusively.

Japan

Quite recently Japan has intimated that a conference may shortly be called to discuss the possibilities of governmental control of production and sales in Japan. Such intimations are periodic in Japan whenever the domestic producers and refiners are embarrassed by low international prices on oil products, but may at any time materialize into govern-

mental control and regulation. A law establishing a scale of subsidies for domestic producers has recently been established in the hope of stimulating production.

China

The new Nationalist Party of China is favorably disposed towards a kerosene monopoly and has made several attempts, largely assisted, it is understood, by Russian influence, unsuccessful to date, to establish such a monopoly. In Canton, each 10-gal. case of kerosene is subject to a tax of two Mexican dollars (approximately U. S. $0.94) further subject to special arrangement with the tax-collecting officials. Within the past month a tax approximately one-half this amount has been established in Central China, subject to the usual arrangements.

Australia

The Australian government through the Commonwealth Oil Refiners Co., Ltd., has subsidized the refining and sale of oil products for a number of years at a considerable expense to the public treasury.

Mexico

Government control of the oil industry in Mexico is apparently in the process of readjustment. Not the least effect of Mexico's difficulties with governmental control of the oil industry as regards the United States has been the spread of the Mexican policy to such South American countries as Argentina, Chile, Colombia and Peru. These countries seem to be on the threshold of untold development of their oil resources, as yet unproved but presumably of great economic importance.

South America

Chile, by an amendment to Article Five of the National Mining Code, which reserves all guano and nitrate of soda deposits to the State, now includes all petroleum deposits, and all petroleum concessions and claims now in force that are not developed within one year from Dec. 26, 1926, are cancelled and revert to the State.

According to unverified press dispatches of January 27, a new petroleum bill passed by the Chilean Chamber of Deputies suspends indefinitely the granting of petroleum concessions to other than Chilean subjects, while the government has allotted funds for a certain amount of explorational work to determine the actual extent of petroleum resources.

A recent bill for the encouragement of the domestic coal industry in Chile has passed both houses of the Chilean Congress and is now awaiting the signature of the executive. This bill provides the following rates of duty on petroleum for use in Diesel or semi-Diesel engines: 3 pesos (of sixpence each) per gross ton of 100 kilos until Dec. 31, 1928, and of 3

pesos more for each of the subsequent years, until it reaches 21 pesos per ton, which duty shall continue in force permanently after Jan. 1, 1935.

Proposed new petroleum legislation in the Argentine leans toward a nationalization of production and all sales privileges to be delegated to a monopoly. A sales zoning scheme for the products of the government refinery is now in existence. A considerable legislative battle to decide the question of national versus provincial rights must be settled before any such national legislation may be enacted.

Brazil has a bill now pending in Congress to clarify the amendment to the Constitution adopted in 1926, which declared all mineral rights to be the property of the nation. Included in this bill are a number of regulations governing petroleum exploration and development which show a tendency to Federal control.

In this brief outline, slight mention has been made of the innumerable restrictions placed on the oil trade abroad by means of special tariff discriminations and the multitudinous variety of taxes on production, storage, sales and consumption.

Tendency to Develop Petroleum Refineries Outside of the United States

In recent years there has been a very decided tendency to develop a petroleum refining industry in many foreign countries. While few countries have developed actual refining capacity that is immediately affecting our petroleum export trade, the indications for the future are not so promising.

Two outstanding examples of this development are England and the Argentine. Preliminary figures for England for 1927 indicate that British consumption of liquid petroleum products excluding bunker fuel oil is approximately two billion American gallons, which represents an increase of 12 per cent. above the consumption for 1926. The increase is accounted for chiefly by larger imports of crude oil for domestic refining. The imports of refined products are about 2 per cent. larger with American participation, some 60 per cent. of the total against 57 per cent. during the year 1926. The proportion of the total British petroleum consumption furnished by the United States declined from 53 to about 50 per cent., due to larger crude oil receipts from sources other than the United States and despite larger actual imports of oils refined in the United States. American participation in British petroleum trade during 1928 may expect certain limited increases in refined oils, but a progressively increasing total of British requirements probably will be supplied from other sources with higher crude-oil imports for domestic refining an increasingly important factor.

The British Board of Trade *Journal*, a government publication, gives some figures which illustrate the rapid growth of the petroleum industry

even in countries which produce no petroleum. As recently as 1913 Great Britain imported only 1,000,000 gal. of crude petroleum, getting practically all her petroleum products from abroad. Then importations of crude oil, to be refined in Great Britain, began. They have since risen steadily until the 1,000,000 of 1913 has grown to 539,000,000 gal. in 1926. Of this the greater part came from Persia, with Venezuela, Mexico, Colombia and the United States together furnishing about one-fourth of the petroleum.

Imports of gasoline into Argentina for the first nine months of 1927 show a decrease of 244,000 bbl., or 12.7 per cent., over the same period of the preceding year. This decrease is undoubtedly accounted for by the increased supply available within the country as a result of the government operation of the 12,000-bbl. refinery at La Platanear, Buenos Aires.

Spain has included as a part of the Royal Decree establishing the Petroleum Monopoly, referred to previously in this paper, a provision that within a period of five years from Jan. 1, 1928, the Monopoly Concessionaire must develop sufficient refining capacity in Spain to supply 80 per cent. of the domestic requirements of refined petroleum products.

France, by the same proposed legislation to regulate oil imports, also includes a provision to stimulate the importation of crude oil for the rehabilitation of the French refining industry.

Some time ago a large American oil company, active in Colombia, announced its intention of establishing a sizable refinery at tidewater in Colombia, probably near Cartagena. By the recent Emergency Petroleum Bill of Colombia, the Colombian Government indicates an intention to build and operate a governmental petroleum refinery. Whatever the outcome in regard to petroleum legislation at the next Colombian Congress, no additional refining capacity there will disturb American export trade during 1928, although it must be expected in the near future.

The Mexican Eagle Oil Co. (Royal Dutch Shell) is building a sizable refinery at Aruba, Dutch West Indies, to process Venezuelan crude oil. Indications are that American interests will shortly establish a large refining capacity either in the same place or in Venezuela. The Venezuelan Government is particularly desirous of developing a domestic refining industry to secure larger benefits to the national economy from the remarkable development of Venezuelan petroleum resources.

In Peru there is considerable talk of the establishment of a government refinery. While it is understood that negotiations are in progress, the outcome is too problematic for further discussion at this time.

The remarkable development of petroleum refining in Canada is already indicated in the increasing imports of crude oil into that country coincident with decreased importations of gasoline and a constantly increasing gasoline consumption.

Russian Petroleum Exports

Russian oils exported to European markets which, as we have seen above, consume over 47 per cent. of our total export of refined oils, have been an important factor in depressing export prices to their present low levels. This has resulted more from Russian export policy than the quantities involved. Oil represents 30 per cent. of the value of all Russian exports, and for the fiscal year 1927 amounted to some 2,000,000 metric tons, or approximately one-fifth of the total Russian production. Approximately 10 per cent. of Europe's petroleum consumption is now probably supplied from Russian sources.

The usual economic theory of petroleum exports is that export represents the surplus of domestic production over domestic demand, and so may be considered as a secondary although vital function of the petroleum industry. In practice Russian policy reverses this theory and export becomes a primary consideration of the oil industry.

Since the ratio of exports to production for the last five years has been approximately 1: 5 under this condition, this ratio would seem to be the economic limit of Russian oil exports under the existing system of Russian economy. The increasing demands of domestic consumption tend to absorb any increases in total production.

Among the factors which tend to prevent any radical change in the volume of Russian oil exports may be listed the inadequacy of refining, transportation and port facilities, which in turn follow upon the inability to finance this State industry so as to provide for its natural and progressive development. This status quo may, of course, be upset at any moment when and if petroleum credits to the Russian petroleum industry by foreign capitalists are granted. The fact that such a procedure would probably precipitate an international crisis would seem to be only a slight deterrent.

While the probable volume of Russian oils to be exported in 1928 will be slightly in excess of two million metric tons, the distribution of this oil is subject to political expediency rather than commercial economics, and is consequently subject to abrupt changes.

For example, we have seen that agitation for the establishment of a petroleum sales monopoly in Turkey proceeded hand in hand with negotiations for the exclusive utilization of Russian oils. A publicity campaign in England is being accompanied by sizable decreases in the importations of Russian oil. A large-scale price war is being waged in India at present between American and British interests over the importation of Russian oil.

Russian oil exports are of such immediate vital concern to the Russian nation that it may safely be assumed that Russian oil displaced from one individual market will immediately be dispersed in others.

Petroleum Substitutes

There is considerable world discussion of the possibilities of petroleum substitutes such as the popularly known "oil from coal," shale oil, and alcohol fuels. Of all, the Bergius "oil from coal" process in Germany is the only one from which the actual commercial operations of the process give promise of quantitative production.

Germany imports about 1,500,000 tons of liquid petroleum products annually, an amount that will increase progressively in coming years. The next year's production of oil from coal by the Leunawerke is not expected to exceed 100,000 tons. Further production contemplated by Gesellschaft fuer Teerverwertung in a plant under construction at Duisburg-Meiderick, will have an annual capacity of 50,000 tons. A speaker at the meeting of the German Society of International Economics in Berlin in November prophesied that in 10 years Germany will produce 2,500,000 tons of oil from coal annually or enough to cover its demand at that time, this expansion to come from additional plants to be laid during the decade.

Increased Oil Production Outside of the United States

Increasing oil production in South America and Irak promises first to displace American oil exports to South America and the Near East, and the surplus to supersede a large portion of our exports to Europe, the Far East and Canada. While it may seem premature to discuss the effects of commercial production by the Turkish Petroleum Co. at this time, to a large degree the recent French legislative proposal for establishing a tariff differential in favor of crude oil for domestic refining was based on the expectations of the French group participation in the Turkish Petroleum Co.

Production of South American countries in 1927 with a conservative estimate of probable production in 1928 are given below:

	1927, Barrels	1928, Barrels
Venezuela	64,000,000	110,000,000
Colombia	14,600,000	20,000,000
Peru	9,900,000	10,000,000
Argentina	8,500,000	8,500,000
Trinidad	5,200,000	5,200,000
Ecuador	450,000	540,000
	102,650,000	154,240,000

Closer Coördination of Foreign Competition

The two most important foreign competitors of American oil-exporting organizations are the Royal Dutch Shell Group and the Anglo-Persian Oil Co., Ltd. The expansion and closer coordination of the two promises a greater economy and efficiency of operations, which indicates a proportionately increased intensity of competition to American companies. The Royal Dutch interests have recently purchased the refinery property of John Fells, Ltd., in Australia and the Columbia Oil Co. in New Jersey. The Anglo-Persian Oil Co., Ltd., has entered the Swedish market on a national scale. The Burmah Oil Co., Ltd., of Burmah, and the Asiatic Petroleum Co. Ltd., of India (Royal Dutch Shell) have recently merged their interests for India. The intimate association of the Anglo-Persian Oil Co. and Royal Dutch Shell interests in the Turkish Petroleum Co. have been previously noted.

Summary and Conclusions

The year 1928 promises to develop marked changes in the volume and direction of United States export trade in petroleum products. In 1927 we have noted an increased volume of products exported simultaneously with sharp depreciations in values. In a large measure these greatly lowered values are a direct result of a world-wide excessive production of oil, but perhaps of slightly less importance are the increasing sales of Russian oil abroad at prices and terms incompatible with the prevailing economic practices of practically all other countries.

This condition is further aggravated by excessive competition for export business among the large number of smaller refiners in the United States in times of overproduction which under present conditions in the export market, amounts to an establishment of market at constantly lowered prices, while the actual business goes to a competitor operating under a unique form of national economy. The resulting prices in turn tend to depress domestic quotations.

The tendency to sales monopolies for oil and the legislative control of the industry abroad has been noted. The effects on American exports are immediate and direct. To a large extent these monopolies are formed for reasons more political than economic. Supplies are usually drawn from sources more intimately related to the monopoly countries by politico-financial alliances without regard to the natural laws of supply and demand on the international market. Examples of this are seen in Turkey, Spain, Greece and possibly Italy, all of which under normal conditions have taken a large proportion of their petroleum requirements from the United States but for which at present the product of Russia and Rumania is substituted.

Excessive civil and military disturbances, as well as restrictive taxation in China, coupled with the present difficulties of rival marketing organizations in India, make any forecast for the world's two largest kerosene markets exceedingly difficult. In the former a consumption progressively increasing for years is greatly retarded, and in the latter kerosene from hitherto American and Dutch East Indian sources is replaced to a large extent by Russian kerosene.

The greatly increased refining capacity of certain foreign countries, actual or under immediate consideration, notably in England, France, Germany, Venezuela and Spain, promises to give a greater international movement of crude oil at the expense of United States exports of refined products.

American oil companies engaged in export trade have a foreign investment of American capital of approximately $1,500,000,000 devoted to this trade. It is perhaps needless to point out that the extended development abroad of nationalization, sales monopolies and refining capacity will seriously restrict, if not jeopardize, the continued profitable employment of a large portion of capital.

The influence of Russian oil in the major export markets of the United States, chiefly Europe and the Far East, has contributed in no small measure to the present low levels of export prices. The critical condition of mechanical equipment of the Russian oil fields, further aggravated by inadequate transport and distributional facilities, and the limited availability of foreign credits to improve these conditions, make it exceedingly improbable that any great increases in export volume of Russian oils may be expected in the current year. However, any marked change in the present Soviet oil policy or the availability of any large amount of credits would tend to reverse this situation within a short period of time.

The sharp declines in prices of almost the entire range of petroleum products have minimized the incentive abroad to develop substitute products. While isolated instances of the limited use of alcohol fuels are noted, in few cases are these entirely satisfactory in present-day types of internal combustion engines. Germany is the only country in which the actual commercial production of petroleum substitutes is now occurring. During 1928, it is expected that this production, by applying the well known Bergius process to coal, will total somewhere between 100,000 and 150,000 metric tons of all products, a quantity equal to only a portion of the annual increased consumption in Germany recorded during the past few years.

The greatly increased production of oil in South America, and the probable new large production expected in Irak through the activities of the Turkish Petroleum Co., will undoubtedly cause marked changes in the trend of our export trade. A possible counterbalance to this may be

found in the increasing consumption of oil products abroad which may, of course, proceed at such a rate as to absorb the output of these new producing regions without abruptly displacing American exports.

Each of the factors above referred to as influencing the outlook for the export of United States petroleum products, and doubtless many others, are responsible for the intensified competition existing between large numbers of American refiners and exporters on the one hand and the greater coördination of interests on the part of our foreign competitors. Excessive competition among the American exporters might be alleviated by some form of coöperative exporting, possibly under the Webb-Pomerene Export Trade Act. The tendencies that give most promise of their continued effect on oil exports are so widespread and of such magnitude that apparently they cannot be opposed successfully by our present forms of commercial organization.

ENGINEERING EDUCATION

Petroleum Engineering Educational Problems

Introduction by H. C. George,* Chairman

At the annual meeting of the Institute in February, 1927, we had a comprehensive discussion of Petroleum Engineering Education. This discussion covered basic training and prerequisites, laboratories and equipment, graduate courses, availability of lecturers, geological engineering, petroleum production engineering, refinery engineering, transportation engineering and economics and management. However, there are several phases of petroleum engineering education, which many members of the Institute felt should be further discussed at this year's meeting. The first was expressed by me in a letter to those participating in the written discussion, from which I quote as follows:

"We fell that the question of handling engineering graduates who enter the petroleum industry should be thoroughly discussed.

"During the first five years after graduation from college, how can these young men be best trained to be of the greatest service to the industry and at the same time do work which will be interesting and of a character which will make them feel that they are accomplishing something and making progress leading toward personal advancement?"

Both the written and oral discussion would indicate three groups of opinion; first, those who advocate letting the young engineers go into the industry and take care of themselves without any supervision, direction, or guidance; second, those who advocate the taking of young engineers into the industry and letting them go through all the steps that any laborer or any other man without a technical education would take, but with some supervision, and third, those who advocate that young engineers should be given special training for several years after entering the industry.

Of course all of these different groups are found in most of our industries. The Doherty training school of the Empire Gas & Fuel Co., finds its counterpart in the practice of the General Electric and Westinghouse companies in the electrical industry and the Baldwin and Brooks Locomotive works in mechanical engineering.

* Director, School of Petroleum Engineering, University of Oklahoma, Norman, Okla.

It seems to me that the question of handling young engineers is not only one of company policy, but it also involves the scope and breadth of education and training of the young men involved, and furthermore the differences in their personalities.

For instance, I think it is generally recognized that we have three major types of men going into industry. I have seen it expressed in this way, that we have the mental type and the motive type and the executive or vital type. The vital type is the man who generally has the qualifications which will make an executive. The motive type is the type of man who will make a good superintendent or foreman. The mental type is the type who will make a good consultant, that is a man who will make a good consulting engineer ordinarily, or a staff engineer or staff geologist, but usually I think this latter type is not well suited to the handling of men and the directing of effort.

On the other hand, a man of the motive type may be able to handle men and materials efficiently, but lack in the qualities which make a good executive, which requires in addition the ability to delegate authority and apportion expenditures properly, and to secure cooperation.

The above-listed qualifications for different jobs in the industry are not all qualifications of training, but are to some extent qualities of natural adaptation. Such being the case it would seem that there should be considerable flexibility in the system of training given to young engineers.

There is another fact. If petroleum engineering means strictly the work of an engineer or the work of a consultant, then the field of available positions in the industry is limited to about one-tenth of the available positions for which we would ordinarily expect to train students. For instance, in petroleum production, where there is one job as a petroleum engineer, in the limited sense, there are 10 jobs as field superintendents. In other words, where there is one job for the mental or consultant type of man, there are 10 jobs for the motive or foreman type, and probably with better qualifications and greater opportunities with the latter experience, to develop into the vital type, which generally secures the executive or higher paid positions after years of experience.

Thinking that the greatest number of opportunities in the petroleum industry are found in its operating phases, whether it be in drilling, production, transportation or refining, the Chairman of this Committee feels that all engineering students that have natural adaptation, should spend the summers of their college years in the industry, so that they may "find themselves" at the earliest possible time, even if this means passing through a period of several years of hard, physical work.

It does not necessarily follow that a young man who gives up this hard field work after several months of it, has a less promising future than the man who "sees it through," but it probably shows that he lacks

some of the qualifications that make a good field man, and he may find success in some less arduous pursuit.

The second question was raised by F. Julius Fohs* in his reply to my first letter. I quote him as follows:

"I wish to say that, while I favor discussion on the question of handling engineering graduates and will attempt to take part therein, I favor, in addition to this, a thorough discussion of graduate courses in Petroleum Technology. Last year we stressed undergraduate courses and, while some mention was made of graduate courses, it was entirely inadequate.

"I have in mind two things in this particular—one is that most of the Petroleum Engineering schools today are schools designed for undergraduates and, while they have some graduate courses, the courses are primarily to fit into a four-year period for an undergraduate school. Many of the colleges of the country already have engineering; electrical, mechanical, civil, and mining courses, any one of which would serve as a basis for Petroleum Engineering provided adequate graduate studies, covering specific Petroleum Engineering topics, were offered. Besides this, there are many geologists and mining engineers over the country who perforce may have to enter Petroleum Engineering within the next few years and there should be courses available specifically for such. These courses should be available not only at colleges like yours, but also at certain Eastern and Western colleges that do not now stress Petroleum Engineering. I should like to see both the practical engineers and the professors of non-Petroleum Engineering colleges, as well as those of Petroleum Engineering colleges, invited to take part in this discussion."

The Chairman of this Committee is inclined to believe that for the refinery branch of the petroleum industry there is a broad field for graduate courses and research projects at those of our Universities which offer major undergraduate work in the subject, but that there is at these institutions a more limited field for research work in production and transportation, because many of the problems in these branches of the industry are only susceptible to effective research work when conducted in the field.

The field research work of the U. S. Bureau of Mines and some of the larger oil companies well illustrate this point.

In addition to the undergraduate work, the big demand for instruction in the Departments of Petroleum Engineering in our colleges, will be from graduates from other branches of engineering who wish to secure a year of instruction in the technology of the petroleum industry, which in most cases will be best satisfied by the undergraduate courses already offered.

---

* Vice-president, Humphreys Corpn., New York, N. Y.

Chapter XVIII. Handling Engineering Graduates

DISCUSSION

J. M. Wadsworth,* Okmulgee, Okla. (written discussion).—It seems to me that the young man must first be absolutely sure that the work he has taken up is to his liking and then I would advise that he get into the practical end of it and learn as much about it as he can as fast as he can. For instance, in the refinery business the college man, graduated in chemical engineering, should ground himself by going through the various departments in a refinery and working in them until he is thoroughly familiar with the operating problems. In a short time he would be able to apply many things which appear in the abstract form in his college work and this would open up an opportunity for him to capitalize on them, promoting his own interest.

I do not criticize the present-day college men as a class, but I have found that many of them come into your plant with the idea that mere possession of a diploma should insure rapid promotion; in a short time they are impatient and usually leave. We have found in employing men that the single attribute most difficult to find in them is a lot of energy and whole-hearted interest in the work at hand, and it seems to me that if a man combines these with a careful technical training he should be fairly well equipped to gamble on his future. They must learn that the biggest satisfaction to be gained in life is in their work.

Procedure for Attaining Objective of Young Petroleum Engineer

H. B. Fell,† Ardmore, Okla. (written discussion).—Of course, the first thing to be considered in any proposition is the ultimate objective that is desired to be attained. I presume that the desired objective of most of the young men graduating in petroleum engineering will be that of chief executive of one of the companies in the petroleum industry, or one of the allied industries, or to become an independent oil producer, or oil refiner, or possibly an oil distributor. The next phase then to be considered is the procedure which should most logically be followed to attain the objective of the individual, since in these cases these young men will have been trained in a course in petroleum engineering and it would logically be presumed that the attainment of their objective should be through the operating end of the branch of the business with which they are connected. The operating end is, of course, the department of each branch of the business that develops the resources, or refines the products, or distributes the products, from which the profits are derived, and is a part of any business which is filled with enough interesting work to appease the desires of the most ambitious young men.

In order to get the best possible training it would appear to me that the place for a young man to start after graduation would be at the bottom of that branch of the industry which he expects to follow. For example, if he is going in the producing end he can get no better training than is secured by starting as a roustabout in the field, where he comes in constant contact with the character of work that is necessary

---

* Refinery Manager, Independent Oil & Gas Co.

† President, Simpson-Fell Oil Co.

in the development and operation of oil properties, and at the same time is in continual association with that great group of men who do the actual work in the field, and whose work he will ultimately have to supervise as he is advanced in his line of endeavor. It is quite essential that he should know the life and problems of those men who are actually doing the labor in the field. From roustabout, if he is under proper supervision, he should be changed around to different classes of work, such as pumping, roughnecking on rotary tools, tool dressing on cable tools, some drilling if possible, with both rotary and cable tools, farm boss, and in the case of larger companies, looking after all construction work and installation of mechanical equipment, and then proceed on up to the position of superintendent. It would probably also be advantageous for him to have some experience in the office in working out the engineering problems which confront the oil operator in figuring the greatest ultimate recovery of oil from the properties with the least possible expenditure of money. Five years of work along the lines suggested, including possibly other work which does not come to my mind right at this time, should prepare an energetic, ambitious, honest and loyal young man to accept the responsibilities, at least, of a position as superintendent, and would place him in that position with ample knowledge to hold down its responsibilities, and enable him to work into a position of greater responsibility.

This procedure could, of course, be allowed in other branches of the industry, or in allied industries, but the fundamental principle would be just the same.

One very important factor that is not always recognized by the young graduate is the fact that a varied experience is of more value to him than the immediate wage, or salary, that he may receive at that time, and very often young men make the mistake of looking solely at the immediate compensation that they are going to receive rather than the ultimate benefit that they are going to derive from the particular work that they are doing. I found this to be quite true in the first few years after my graduation from college when I was working for the Lehigh Valley Coal Co. I was desirous of being transferred from one department to the other for the purpose of endeavoring to acquire knowledge of the work of the various departments, and one time in particular in doing this it was necessary, in making the transfer, for me to take a salary that was considerably less proportionately to what I was getting. I was glad to do this because I felt that the ultimate advantage would more than outweigh the loss in salary, and ultimately this proved to be true, but there were quite a few of the young men who were unwilling to transfer around under those conditions. I noted at the end of five years after my graduation that by following the policy that I had that the salary I was receiving at that time was considerably more than the salary being received by those who had stuck to one department.

Necessity of Apprenticeship in the Field

A. C. Rubel,* Compton, Cal. (written discussion).—I feel that a graduate petroleum engineer, or any other graduate engineer, who intends to enter the development or production end of the petroleum industry must go through a period of apprenticeship in the field in order that he may obtain a practical working knowledge of conditions and, what is more important, a practical working acquaintance with the men in the field. In the past our greatest difficulty has been that our petroleum engineers or so-called technical men could not meet on common ground and discuss in common language the every-day problems with the men in the field, who are actually working on them.

I feel that an engineer's stock-in-trade is records and that the success of his work can only be in proportion to the accuracy and completeness of his records. In order

* Petroleum Engineer, Union Oil Co. of California.

to obtain these records he must depend almost entirely upon the man in the field and unless this man has some understanding and sympathy with the purposes of the engineer, he is not going to furnish that engineer with the proper records and the proper information to give the maximum results. I am inclined to place the blame for the lack of cooperation on the engineer rather than on the men in the field, as I have yet to find an instance where the so-called practical man could not be won over if properly approached by the engineer.

I feel that the logical way to put our technical graduates through the mill is to start them either during vacation or at the end of their college course on the roustabout gangs in the field where they will either sink or swim in their contact and relation to the field men. It has been said in criticism of such a plan that some of these boys are high-spirited and would become discouraged and have their spirit broken by having to go through such a period of apprenticeship and it has been compared to hitching a high-spirited race horse to an ice wagon. My answer to this argument is that what the petroleum industry needs is not high-spirited, temperamental men but the steady, hard working type who are able to stand the gaff. Instead of the high-spirited race horse we are in need of the broad shouldered truck horse, and the quicker the man who is temperamentally unfit for oil field work is eliminated, the better it will be for both the man and the industry. I would let the young graduate go through the roustabout gang, rod gangs and drilling crews in the regular manner, leaving his advancement entirely up to his own efforts and the judgment of his superior. This may seem a little harsh but looking at it from the standpoint of financial gain to the individual, field jobs even of the labor type will pay better, and offer at least equal opportunities of advancement, than the average job in that line of endeavor requiring the same amount of education and experience. A gang pusher, for example, in California receives approximately $225 a month. A man with initiative and ability to assimilate what he can learn has a reasonable expectation of advancing to the job of gang pusher within two to three years in the field. What profession can offer to a young graduate the same opportunity within 2½ to 3 years after his graduation? A drilling job will pay from $275 to $350 a month and there is a reasonable expectation of a man reaching this point within 4 to 5 years. This, I believe, will compare very favorably with the opportunities of advancement in any other line of endeavor and thus it will go clear up the scale.

I believe one of the greatest criticisms of the college trained man has been that he rather expects to be the recipient of special favors and special consideration because of his special training. In my opinion this training merely supplements his natural ability and the practical experience he may gather and gives him a considerable advantage if he is the proper type of man, in the competition for his everyday livelihood. I believe that he should start at the same point and compete under the same conditions with every other man in the field, and if he does advance more rapidly and farther than the other man that it should be because of the merits which he displays and not because of the fact that he is a technical graduate.

I think you will find that a number of the companies are putting this plan into practice with the idea of gradually making their entire organization as nearly as possible technically educated and trained men, but not necessarily engineering graduates unless such men can demonstrate that they are superior.

Importance of Proper Training for Young Graduate

L. B. Holland,* Bartlesville, Okla. (written discussion).—As you know, I have been very greatly interested in the method of handling engineering graduates after

* Petroleum Engineer, Phillips Petroleum Co.

graduation so as to fit them into oil company organizations to the greatest advantage of the organizations and to the individuals.

There undoubtedly has been in the past, and yet exists in certain districts, particularly some of the older fields, a tendency to look with disfavor upon any very radical change in the customary methods of the management of oil companies. This tendency is at the present time undergoing an evolution which has been caused by demonstrations of the inadequacy of the older methods. As a result the oil industry is today looking to its technical men for a solution to many of its numerous problems.

The task of fitting a young engineering graduate so that he will be of value in an oil company organization is no small one. He can only be of the most service when he fully understands the field problems, speaks the field man's language and visualizes the problems as they arise from both a technical and practical viewpoint. There is but one method by which a technical graduate can get himself so trained and that is by going into the field and actually doing the various tasks which are handled by the field men.

In order to obtain as varied an experience as possible in a given time it would be very desirable to have the field work of all young technical men directed by a competent engineer who himself has gone through the field training and preferably has also had several years' experience in development and production work. At the same time each graduate should take his place as a member of the department in which he is placed during the period of his work in the department. The period of time spent in each department should vary with the scope of work covered.

The total time which a graduate should spend in familiarizing himself with field operations should be sufficient that a ground work could be built up to intelligently handle any problem which might later arise.

One of the difficulties which has arisen in certain companies giving training of this nature is that the scale of pay for the graduates is so small that the graduate is willing to accept almost any position which might be offered so long as the scale of pay is higher. As a result numbers of engineering graduates may be found who are merely in clerical positions with very small chance of working into positions in which their engineering training would become valuable.

Another difficulty, which is becoming less as time goes on, is that some of the practical men in the field feel that the young engineering graduates are imposters and for that reason any information which is secured by the graduates is obtained in spite of rather than because of the help of this type of oil field workers. In order to eliminate any friction which might arise, it is necessary that a considerable amount of tact and diplomacy be used by the engineer who is directing the field training of the younger graduates.

Oil Field Hardships Discouraging

A. M. Hepler,* Ardmore, Okla. (written discussion).—Our greatest trouble with young men, after graduation from college has been that they do not stay even one year, let alone five years. It seems to me that these young men have not had any contact with the oil country, prior to taking up work there; that its mode of life, hardships and general difference from the life they have been used to, proves discouraging to them before they have stayed at the work long enough to really appreciate its advantages. We are always glad to give these young men a trial and those of them who have taken an interest in the work and have stayed for a sufficient length of time, have made progress and personal advancement long before their first five years have expired.

---

* Superintendent of Production, Humble Oil & Refining Co.

We have found that many of them are apparently not interested in anything pertaining to the oil business; their interest apparently being taken up by athletic or social life, although we have moved them from one department to another trying to find the line of work they were most suited for. This was not true in all cases as I have found a few of them who were as much interested in the mechanical part of pulling a string of rods as they were in the oil-gas ratio of a flowing well.

I believe producers in general want to do everything practical in the way of getting young men started in the oil business and a real liking of the business for itself is essential as a starting point. This might be built up while these men are in school by sending them out for short periods of time to practical men in the business, who would allow them to help work out operating problems that may be on hand at that time.

E. L. Estabrook,* New York, N. Y. (written discussion).—The question of handling engineering graduates who enter the petroleum industry during the first five years after college seems to me to be easily answered. Put them to work at any hard job and let them work out their own salvation, would be my answer. Should the fact that a young man has had the opportunity to attend college entitle him to any particular favors after he gets out to work? The whole tendency of the college is likely to be toward causing the young man to think that he is entitled to favors and the best way to get the idea out of his head is to make him fight all his own battles in learning the petroleum business. No doubt such a course will cause many embryo petroleum engineers to abandon the profession for some less arduous one but I doubt if that is to be considered as a real loss to the industry.

The only justification that I can see for asking, "during the first five years after graduation from college, how can these young men be best trained to be of the greatest service to the industry and at the same time do work which will be interesting and of a character which will make them feel that they are accomplishing something and making progress leading toward personal advancement," is that there is such a shortage of young engineers that the industry is compelled to coddle the few that are available. I have not understood that this is the situation and even if it were I cannot agree that coddling is the proper answer. A generous pay check and all the hard work they can stand is likely to be much more effective in attracting young men to the petroleum industry than "making the work interesting" during the first five years.

Knowledge of What He Wants to Do Helpful to Graduate

J. J. Allison,† Ponca City, Okla. (written discussion).—Briefly, the consensus of opinion seems to be that the graduate petroleum engineer himself can be immensely helpful in solving the problem of his future disposition if he knows what he wants to do and is willing and anxious to start in immediately. Otherwise, valuable time is apt to be lost before the new employee discovers his own preference for his future work.

It also seems to be the consensus of opinion that the preliminary training of the young engineer should be the complement of his ultimate work. I mean that if he is particularly interested in the chemical phases of petroleum refining and intends to make the laboratory the ultimate goal, his preliminary work should consist of a brief period in the laboratory to learn how the plant is controlled through the laboratory, after which he would be transferred in turn to the various departments to familiarize himself with operating problems, this training, theoretically at least, enabling him to become a highly useful member of the research staff.

---

* Consulting Petroleum Engineer, Pan American Petroleum & Transport Co.

† Assistant Manufacturing Manager, Marland Refining Co.

Should his desires incline him toward a position as an operator, his preliminary training should consist of a year or two in the laboratory where he would become thoroughly familiar with testing and control work. Then would come a period spent in the various operating departments after which he would be assigned permanently to one department, the choice depending upon his own preference, and the one in which he had shown the best results in his preliminary work.

The same general rule applies if he is more particularly interested in the mechanical and construction instead of the chemical phase of the work. If he wishes to become an "outside" engineer, then his preliminary work would consist of a year or two in the office and drafting room. If he wishes to become an "inside" man then he should spend at least a year or two in actual construction work. In either event the young engineer must acquaint himself with the general system of accounting used by his company, with particular emphasis on the phases most closely associated with his own work. He must learn everything that he can about costs, both as to estimating before work is started and also after construction is complete. This should be a period of reclassification of values when the young graduate will realize the true meaning of the word "commencement," that his education truly has only begun. He must learn how much of the theoretical knowledge gained in school must be discarded and how much he must keep and develop to aid him in solving practical problems.

Another important characteristic that the young engineer must develop, regardless of whether his choice of work ultimately leads him to an operating, chemical or mechanical and construction job, is a sense of responsibility. It is true that his immediate superiors can greatly accelerate the development of this sense by assigning him jobs for which he is solely responsible for the planning and execution, but he can do much himself in attaining this end by his willingness to accept, rather than evade, responsibility. In my opinion the only way to develop this sense of responsibility is to be responsible. It cannot be attained by merely wishing for it.

Graduate Engineer Must Train Himself

C. V. Millikan,* Tulsa, Okla. (written discussion).—The training of the engineer following his graduation is probably the most difficult problem facing those who must have under them this class of men. Unfortunately with few exceptions it is necessary for the graduate to take upon himself his own training and, this being just the reverse from the training which he got during his college days, he is slow to realize the necessity of acclimating himself to this different condition.

Therefore, handling a graduate engineer resolves itself into an individual problem. He must train himself. While as a student he was given certain problems to solve each day, after graduation he not only has problems to solve each day but he must find those problems for himself. If he can do this, his superiors will soon find that he is more than a piece of machinery in the organization and will assign broader duties with which will arise larger and more complicated problems.

If a graduate when accepting his first job were made to *realize* that that job carried with it responsibility and the necessity to show initiative or lose that job no doubt most of them would do better and advance faster. As a matter of fact, these things are expected of every graduate when he is employed. But the unfortunate part is that he is continued on the pay roll when these desirable qualities fail to develop. He is retained because his work is efficient as a part of the "machinery" of the organization. The individual would often be done a favor of inestimable

* Petroleum Engineer, Amerada Petroleum Corpn.

value were he requested to resign as soon as he failed to show the qualities that were expected of him at the time he was employed. No executive feels himself obligated to give a man special training in practical engineering just because that man has specialized in that training during his college course. In order that he shall receive such training he must first show that he is capable of using such training. To prove this requires more than conscientiously and consistently performing the daily work which is laid before him. This is of course essential, but he must also show initiative. He must have and develop the ability to anticipate developments and to know what to do when unusual circumstances arise and then do it. He must accept responsibility.

Some of the larger companies have established a practical training school which is open to men immediately following completion of their technical courses. Such a course is much better for the student than for the company maintaining it, and its value to the student is often overemphasized. If the engineer upon completion of his technical course is endowed with the ambition and initiative that he should be, he will obtain the equivalent training on his own initiative. If he does not have these essential mental attitudes it will take more than a training school to give them to him.

A contributing factor to the already difficult situation of educating the graduate petroleum engineer is the present demand for men with that technical training. The demand is far in excess of the supply, which is resulting in placing greater responsibility on many men than they are trained to perform. Such a situation is regrettable not alone because it reflects indirectly on the men who are qualified by training but it makes the problem of training the younger graduates even more perplexing.

A. E. Pew,* Marcus Hook, Pa. (written discussion).—Engineering graduates who have obtained a position with the Sun Oil Co. in refining have been located in the General Engineering Department or in the Development Department. For the first year, they are more or less assigned to routine work as we have never found these graduates to have any practical knowledge of the oil business or the problems involved. We, accordingly, feel that before they can intelligently work on any problem, they must become thoroughly conversant with the general characteristics of the various petroleum products and their scheme of manufacture. During the year, the man usually shows a particular bent for some line and, if possible, we try to permit him to follow it out. Should he not show development he is allowed to resign. However, we do not have any very definite policy in regard to this matter, usually arranging our procedure in accordance with the particular individual involved.

Requirements for Engineering Positions

F. W. L. Tydeman,† Wood River, Ill. (written discussion).—In considering this problem, the first question is: *Just what kind of work are we training these men for?* In the refinery with which I am connected, the general answer to this question is that these men should eventually be able to hold positions on the order of Refinery Superintendent, Assistant Superintendent, Chief Engineer, Chief Chemist and the like. The next question is: *What are the requirements that a man in these positions should fulfill?* If we ask that question of different people, and summarize the answer, we find that we want a paragon of virtue, wisdom and ability, who embodies all of the good qualities listed in the various books and articles on personnel selection and

* Chief Engineer, Manufacturing Department, Sun Oil Co.

† Refinery Manager, Roxana Petroleum Corpn.

management. I shall not bore you with copying from these lists, but I shall try to put down some of the qualities which seem important. They will occur to me perhaps mostly because they have been found missing in certain instances. It is human nature to want to criticize the bad points more than to relevate the good points. We are inclined to believe that all people and things should naturally be good, and we talk about them mostly when they are not. If I succeed in making my criticism constructive, however, perhaps the time taken in reading this will not be entirely wasted.

In the first place of course, we want honesty, and that is hardly a matter for education. At least, not when men have reached the age of graduate engineers. Closely allied to it is loyalty, for which the same can be said, but in both of these qualities it is at least necessary that the superiors, under whom these men work, set them a good example.

As item No. 3, I would place cooperation. We stress this quality very highly in our organization, and we have perhaps let out more men because they could not or would not cooperate than for any other single reason. It does not make any difference how wonderfully equipped they are technically, if they cannot apply this equipment in the form of team work, they cannot do very much good with it, especially, of course, in general refinery work. There might be an occasional exception in research work. Sometimes lack of cooperation is a trait of character which is hard to eradicate. In other cases, it is a matter of habit or forgetfulness, perhaps caused by previous education or environment, and can be overcome by proper management.

Cooperation is a mutual affair in that those who tend to cooperate freely usually manage to get good cooperation from others. From this, it should be a short step to the successful management of others. Tactfulness is an important asset in this connection.

Neatness and dependability often go hand in hand, but are not always easy to find. We want men who can handle matters without being continually checked up and reminded. Add common sense and good judgment and reasonable initiative, and our paragon is almost ripe. Anybody who has filled the bill to this extent will almost certainly not be devoid of a fair amount of intelligence. Other things being equal, I prefer a man with good basic training in mathematics, physics and chemistry, and the ability to use it. Otherwise, I prefer the man with the proper moral and mental makeup, and I'll take the chances that he will educate himself not only up to his job, but beyond it. I do not want to minimize the importance of good technical training, but I want to stress what is, in my opinion, the greater importance of character.

There is one accomplishment which present-day education does not seem to stress sufficiently, and that is the ability to express one's self. People may realize that knowledge is useful only if you use it, but they apparently fail to realize that using it often implies telling somebody else about it, and that a lot of the effect depends on how the story is told. Many good men would be still better if they could only write clear letters and intelligible reports. Neglecting the reader's point of view is the usual and most serious sin, with bad grammar and verbosity as runners-up. Some time ago Dr. E. H. Leslie, called my attention to T. A. Richard's book, "Technical Writing."[1] A number of us here have found it very useful.

Training Course Supervision a Problem

Now then: *How are we going to steer our young hopefuls toward this goal of being the almost perfect refinery executive?* Some years ago we had an idea that a sort of "special apprentice course" might be desirable. The American Steel Foundries were kind enough to let us study theirs, and we attempted to work up one of our own. We

[1] John Wiley & Sons, Inc., New York.

have not been able to put it into general practice as yet. For one thing, such a training course requires a supervisor who follows up the work of the students in the different departments, assists these men, guides them, teaches them and reports upon them. Such a man would have to possess the various qualities mentioned above as required for a good executive; besides that he would have to know refinery theory and practice from A to Z, and he would also have to be a good teacher. We have not found such a wizard yet. And whenever we have a man who approaches the ideal, we find that we need him badly on direct production or engineering work and we put off our educational scheme. A somewhat similar accident usually happens to the promising student; he is claimed by some understaffed department or for some rush job and he has to attend to his own further education the best he can. So at the present moment our "school" consists of one student, and he is a graduate chemical engineer who had some three years' experience elsewhere as process chemist. The schedule outlined for him takes in about three years of work in all of the different departments in the plant, including jobs as gager, fireman, pumper, stillman, treater, pipefitter, clerk and so on. After this he will spend a month in each of the four divisions of the Laboratory, and finally he will have four months in the Engineering Department as a sort of understudy to the various Assistant Master Mechanics. He will have to depend on guidance from the men in charge of the various divisions where he works. This will not always be satisfactory, because a man may be very good in working at his specialty and at the same time be a poor teacher, or he may not have time to teach when it should be done.

Another stumbling block with these training courses is the necessity for individuality. Every man has a different mental makeup and different preliminary training and experience, and the course should be suited to the individual in each case. One man might need laboratory experience first; another one last. One might need a lot of it and another one little or none because he has already had it, or because he takes to it like a duck takes to water. There is one thing, however, that I believe is important in most cases, and that is a considerable period (say six months to a year) spent in the ranks. And not only *in* them, but *of* them; working the same hours, subject to the same discipline, suffering the same unavoidable hardships. The reason for this has been expressed so aptly by L. E. Smith[2] that I will quote him:

"Not long ago the writer entered the office of a man who is nationally known for his authoritative knowledge of the producing division of the oil industry. He was at that moment in the act of advising a young engineer, just out of school, as to the best way to get into the oil business.

"'The only thing I can tell you,'" he concluded the interview, 'is to get out and get dirty. The only way you will ever know how to produce oil is to get a job producing it; the only way you will ever know the kind of men you expect to work with and over is to go and live their life for a long time.'"

The argument remains the same whether we speak about producing or about refining.

We have not been able to practice consistently what we preach, in this respect, either. Too often we hire young chemists or engineers fresh from college and have to put them immediately on special work. Although we do not have a real training school for these men, we do keep special track of them by having the Employment Department report on them at regular intervals during the first few years of their employment with us. The Employment Department merely centralizes this information obtained from the departments where these men work. It is supplemented by personal discussions between the superintendent and the men's immediate superiors.

[2] L. E. Smith: Shirt Sleeves Method Only Way to Learn. *Natl. Petr. News* (1924) **16**, 69.

Interest in His Work Up to the Man

Before trying to answer the question, "*How can these young men be best trained . . . and at the same time do work which will be interesting and of a character which will make them feel that they are accomplishing something and making progress leading toward personal advancement?*" I would like to ask: *How can we get young men that will take an interest in their work beyond the present size and frequency of their pay checks and the "possibilities of the future?"* If I can solve that question, the previous one will evolve its own answer. I am convinced that in most cases where the men complain of uninteresting work, or lack of accomplishment or advancement, the trouble lies with the men themselves rather than with the work or with the organization. There need never be a lack of interest for the man who can develop his interest. The gager can study gaging and tanks and layouts and emulsions and the products he handles; the pumper can study pumps and engines and steam and pipelines; the stillman has whole fields of heat transfer and fractionation before him; even the unskilled laborer could dig out a bushel of interesting problems directly connected with his work, if he would only use his head. We will help them gladly whenever we can do so. But many young men of today do not want to use their heads or anything connected with their work beyond the immediate necessity of doing that work in such a way as to avoid getting fired. When the whistle blows they are off to the pool room or the dance hall or some other kind of recreation. They dislike hard work and dirty work, and prefer nice white-collar jobs with rapid promotion towards high salaries and mahogany furniture. How can they find interest if they will not look for it, or expect advancement if they will not work for it?

What is the result? Our Assistant Superintendents are men who grew up from the ranks because they showed character and ability and dug hard into their jobs. The college graduates who would have had their positions, other qualifications being equal, quit long ago because the work was too hard or too dirty or not interesting, or the pay was too small or promotion did not come fast enough. Those who did not quit got fired because they were arrogant or lazy or could not handle men or were too temperamental or could not think straight or could not organize. Happily we are having better luck with some of their successors, and the men from the ranks will have to be more exceptional than before to keep up with them. That sets a higher standard all around, and should benefit everybody who deserves to be benefited.

In conclusion: It all depends on the men. Let the colleges give us men who are not only well trained in the sciences and in the principles of their application, but who are also men of good character and a sensible outlook upon life and work, and promotion will take care of itself.

E. W. Wagy,* San Francisco, Cal. (written discussion).—Whenever practical, an engineer should come in contact with the industry as often as possible during his college career, probably during his summer vacations, in order to try to definitely settle the question in his own mind as to what particular line of work he would like to follow. In this way he can be guided in his choice of college courses much more intelligently and hence be in a position to become of value to a company at an earlier date than one who has not attempted to settle this important question for himself. In any event, there are general courses which a prospective applicant must choose during the final two years of his college work. I mean, for example, that an organic chemist could not expect to follow petroleum production engineering without readjustment, nor could a mining, mechanical or petroleum engineer carry on the work which an organic chemist would do with any degree of skill.

---

* Department of Economics, Standard Oil Co. (California).

An engineer who has decided upon the general division in the industry which he desires to follow, usually can take up that particular work in a company without difficulty. On the other hand, if an engineering student has not had the opportunity to come in close contact with the industry, or at least has not been able to make up his mind as to the definite line which he wishes to follow, a general course of training in the company will probably be the order of procedure.

With this in mind, I am outlining herewith what I think should be the method followed to secure the most satisfactory results:

On the Handling of Engineering Graduates during Their First Five Years of Experience

I. General Method

In handling engineers during their first five years' experience, the company will necessarily be put to considerable pains and expense, the object being to train the young engineer from the time of his graduation until the time when he can assume a position requiring initiative and responsibility. Notwithstanding that there are many branches of the industry requiring engineers of various training, it is believed that there are some fundamental methods and principles which will apply to all. The first is the problem of selection.

Obviously, much wasted effort could be avoided by confining training to those who are eligible and show promise of making the most of the opportunity. This leads to the consideration of selecting the candidates. The following is suggested.

A. Assume that the chosen men are either to receive the benefit of an organized training course, or are to be dismissed from service at any time that they appear to be disqualified; that is, there is to be no compromise whereby the engineer who fails to meet standards is given some subordinate position for which he could probably qualify. The object of this attitude is to prevent dissatisfaction among those who fail to progress. They are better removed from the organization and such positions filled by direct methods.

B. Decide upon the qualifications of a young engineer for any of the branches.

1. Technical.
2. Personal.

C. Devise a plan for measuring qualifications as exhibited by college experience, individual activity and personality. In doing this, both the scholastic record and college activity should be considered and his personal experience should be viewed in the light of his ability to complete successfully what he has undertaken, rather than simply what he has done. As to forming conclusions by personal impression, there is necessity, of course, for employing a person skilled in making such conclusions.

D. Make entrance to the training course highly desirable by causing it to be distinctly competitive, so that it will appeal to those who desire to excel.

E. During the first year, make the appointments decidedly tentative, under some such plan as

1. First three months, preliminary qualifications.
2. Second three months, further qualifications.
3. End of first year, approval or disapproval for the next year's work.

It will be seen that this gives three regular and expected opportunities to select, without ill feeling, certain ones from those who enter the training. Let it be understood that the course is highly competitive; that usually, say, only 75 per cent. of those who start are able to finish, but that the reason why many drop out is because they have not fully made up their minds as to what they want to do.

II. Training in General

A. Divide into branches
1. Production.
2. Transportation.
3. Refining.
4. Etc.

B. Supplement training with organized instruction given during working hours in the first stages and after working hours as this form of instruction becomes progressively of less importance.

III. Training under Separate Branches

A. Petroleum Engineering (for example).

1. *General Field Experience* (1st year).
   (*a*) Warehouse experience—3 months.
   (*b*) Gaging experience—3 months.
   (*c*) Producing experience—3 months.
   (*d*) Field office—3 months.

(During this time apprentice engineers will attend classes conducted by some qualified engineer of broad experience wherein the general theory of petroleum engineering is presented in systematic form. No allowance will be made for students who are not sufficiently prepared to follow the discussions with facility, for these students are expected to be qualified in higher mathematics, mechanics, physics, chemistry and any other sciences which may be deemed prerequisite.)

2. *General Office Experience* (2d year).
   (*a*) Estimating, including engineering economics.
   (*b*) Drafting.
   (*c*) Design.
   (*d*) Application to some problem.

3. *Applied Practice* (3d year).—During this year the apprentice will serve as an assistant to an older engineer who is working either in the field or in the office, the preference being that the year should be divided between the two.

4. *Executive Experience* (4th year).—During this year the engineer will serve either in the field or in the office as a representative of the management. There is much work connected with executive control which can with safety be delegated to such a man as the trainee should have by this time become.

5. *Individual Work* (5th year).—This year will prove whether the selection, training, application, interest and general qualifications of the trainee have been successful. This will be determined finally by assigning him to some problem, or to some duty, involving initiative and direct responsibility. At the end of this time, upon the successful performance of his work, the man may be deemed qualified for swift and further progress.

P. M. Miskell,* Tulsa, Okla. (written discussion).—Our company for a number of years has realized the advantages of men going into the industry with the university education that is necessary for them to carry on properly; and I am attaching to this letter an outline of the Doherty Training School, how it is handled, and enlarging somewhat on the idea as to why it is maintained. If this work can be adopted for the oil industry as a whole, no doubt it will tend to improve its carrying on greatly.

---

* General Manager, Refining Division, The Empire Companies.

Doherty Training School

C. Briggs,* Bartlesville, Okla. (written discussion).—I have prepared and attached for your consideration a brief outline[3] of the purpose and operating method of the Doherty training school. In connection with this outline I might say that while the course is designed to cover a two-year period, the average student remains in the course only about 18 months. Students are transferred from the course to permanent jobs whenever such action is satisfactory to student as well as to the department concerned. However we stress upon the student the desirability of remaining in the course a reasonable length of time instead of accepting the first job which may be offered. It has been our experience that the average engineering graduate has little actual experience in the oil or gas business and consequently has only a vague idea regarding the particular branch of the industry to which he is best suited. Consequently, the training school serves a twofold purpose in that it enables the student to obtain a general knowledge of all branches of the industry, and also enables him to decide on the particular phase of the business which appeals to him most. For these reasons we believe the time spent on the course will pay excellent dividends in the future.

I might also state that we make an effort to keep in touch with all ex-students after they are transferred from the course. We are thus able to place these men in positions of greater responsibility at such time as their progress justifies and as suitable openings occur. In the Engineering Department in particular, and also in other departments to a lesser extent we make a practice of working a man on both office and field jobs if circumstances will permit. By so doing, he secures a well-balanced training and is better qualified to view a problem from all standpoints.

Selection of Staff Personnel

R. H. Johnson,† Pittsburgh, Pa.—Oil companies should be on the alert to get a better staff than their competitors for the same cost. It is absurd to devote much attention to selection of raw material for a plant, and at the same time select the recruits by favoritism or chance applications. Since men are graduating mainly in June, most companies should accommodate themselves to the situation and expect to take on some new graduate engineers each June when the work will permit. In fact it will frequently pay to carry the man on simply relatively unskilled work for the sake of holding him, if nothing more suitable is immediately available. Naturally this work should be of the sort, when available, which would be most useful in developing men.

In my opinion the practice of the leading electrical companies should be emulated and improved upon by the oil companies, *viz.* to communicate with the competent school each spring asking for a list of juniors with data as to marks, intelligence tests, and personality trait ratings. Engage a selection of these men for summer apprentice work. The knowledge thus gained makes it possible to make a further selection of those desired at time of graduation. The student should be definitely engaged at the end of the summer trial and the nature of his probable future assignment stated at that time. I am confident all the schools represented here would be glad to cooperate to this extent with companies.

C. A. Bonine,‡ State College, Pa.—In regard to the Doherty Training School, I know from the experience of our graduates that they do watch men, even during the

* Chief Engineer, The Empire Companies.

† Professor of Oil and Gas Production, University of Pittsburgh.

‡ Head of Department of Geology and Mineralogy, State College, Pa.

[3] See Petroleum Development and Technology in 1926, 865.

period of training and try to put them in the department where they seem to have shown special aptitute. I know in two cases, of men who did not want to be transferred in three months' time to another section. They preferred to stay where they were and were kept there and given permanent work in a short time.

I think we ought to, in some way, call attention in the industry to the necessity for better personnel work as Professor Johnson has said, particularly looking after the men during that first five-year period out of college.

The High Class Mental Worker and the Superintendent Type

E. R. Lilley,* New York, N. Y.—I cannot help but feel that there is a definite division in the types of men entering the industry. I do not know as I should want to go so far as to make an absolutely three-fold division, but it seems that there is a typical mental type of worker and also a superintendent or boss type. These two groups are entirely different from each other. I rather feel that the high class mental worker who is treated in the way that the superintendent type is treated during the first year or so after he comes out of college is going to fizzle badly. While he may be accused of going out of this industry in order to get into an industry where the work is less strenuous, I think if you follow him up you will find he actually goes into another industry where he is less fitted to start, and succeeds. In other words, he drifts out of this industry into another, whereas he might be kept here where he is best fitted to succeed.

I do not think we have the right to say that all the men who drop out do so because they do not receive sufficient coddling. There ought to be some recognition of the distinction between the two groups just as soon as they come out of college.

I am not quite certain where I would put the executive. I have the feeling that the executive is a man who combines both characteristics. He may develop one to a greater extent than the other, yet I feel that such a combination is essential. Necessarily, really good executives are few in number.

W. C. Colby,† New York, N. Y.—How many present are school or university faculty members and how many are representatives from oil companies? I see we are in the minority with only three oil company representatives. Naturally then, the tendency of the discussion would be along lines of particular methods of training petroleum engineers. However, if an oil company is not convinced of the value of a systematic scheme for recruiting and training petroleum engineers, is not the more immediate problem that of selling the idea of such a program to the management? For example, why is it that there are not more oil company representatives in attendance at this meeting? The school men can do very little just within their own group and the other men who need to join in such a discussion as this are not here so that a discussion as to the particular methods of training is perhaps not so important as the problem of stimulating the present oil company executives and junior executives to the value of some systematic plan along this line. Even for the larger companies that idea has constantly to be sold throughout the organization. We are having to do it all the time ourselves. It is one of our greatest problems.

The detail problem of training the men is not really so far-reaching as training our executives to the idea of training employees.

Another thought I would like to cast out is that the problem perhaps cannot be considered as one for all phases of the industry. The particular method would perhaps have to differ as we approach the production end of it, the refining end of it, and possibly that end of it which might be connected with the commercial or management end. We have found it difficult to train our own people for the broader aspects

* Associate Professor of Geology, New York University.

† Standard Oil Co. of New Jersey.

of problems in the industry as a whole. They have to be trained more specifically for one phase of it at first.

Another problem we have had to meet also is the fact that most graduate engineers entering the industry are not refining engineering graduates. They are some other variety and know little or nothing about the problems of the industry. They have probably a little book learning on it but no practical experience unless they have had some work in the industry. They are at a loss to decide which phase of the business they ultimately want to continue in and it is the responsibility of the particular company to guide that student in the particular phase he is best suited for, picking him out on the basis of his personal qualifications perhaps and, of course, technical knowledge too, but taking him on faith as to his future specialization.

Standard Oil Co. of New Jersey Training Plan

The company which I represent has a plan somewhat similar to the Doherty Training School. Our point of view, perhaps, is a little different. We follow a systematic plan of recruiting men from the various colleges and now have about 80 per cent. of them still with us, after a trial of about six years according to the plan. Most of the men have entered the refining end of the business, however. We find that the producing man has a considerably different viewpoint than has the refining man and possibly is harder to educate to the idea we have in mind so that we frankly tell prospective student engineers when they are coming with us that we are taking them on faith, that we can possibly estimate what phase of the busines they may be suited for but that we want to try them out and they want to try us out. We put them through a somewhat systematic form of training but the particular method of training, I think, will also differ depending on the company.

If it is a large company having a training program for all of its employees, as we happen to have, it will be possible for a new engineer to take this special cadet engineering course for perhaps one year and then continue on for as many as five or six years with other training courses that may be available to employees in a local plant or out in the field, or by correspondence, or in various offices so that there is a continuous training opportunity.

But I still think that the major problem is that of educating management to the idea of recruiting and training men to a definite plan.

Earmarking Young Graduate as Member of School

J. M. Lovejoy,* Tulsa, Okla.—I would like to answer Mr. Colby. I represent the class that employs engineers and I am not so sure that the training school idea is good. I think that with the school we put these young graduates out in the field and they are earmarked from the start by the practical men as members of the school. For the first few years of an engineer's life after graduation he can be developed to best advantage by close intermingling with the field men, so that he becomes one of them in so far as possible. If he is in any way earmarked by the management or any favoritism shown him, he will not get along as well with the practical men.

My experience has been that unless the engineer and the practical man have complete understanding of each other they will not get along. The practical man, after all, is the engineer's best friend. The engineer, until he has had several years of experience, cannot lift a hand without talking it over with the superintendent on the ground. He has to have all his ideas checked by these practical men. I think that sending him through a school is not entirely satisfactory. I am speaking purely from the point of view of production engineering, not from the point of view of the geologist or training a man for any other branch of the business.

---

* Vice-president, Amerada Petroleum Corpn.

I believe the real difficulty of young production engineers today is that they do not like the life. They have to live in a little camp or some little town and they will not stand the gaff. I do not blame them particularly. It is not as pleasant a life as they might want and if they do not like it the best thing for them to do is to get out. I do not know how the companies can make it more attractive for them.

The Amerada has employed a great many young engineers and most of them fall by the wayside. They stay at it six months or perhaps a year and it does not hold them. The life is too rigorous for them and they leave or perhaps they look ahead and see that if they do their work and are good men in five years time they might become a farm boss with a salary of $200 or $250 a month. That does not attract them sufficiently and so they think they had better direct their efforts in some other direction.

Of course, we know that the man who does develop into a real production engineer is not going to stop very long as a farm boss, although, in my opinion, he should go through that experience. He should start as a roustabout and work up so that he can become first of all a gang pusher and finally a farm boss and possibly a step further than that. Then, when he has learned the life of the practical production man and lived that life with him in every respect, until he talks his language, he can go out and direct work where practical men are concerned.

I have the utmost respect and confidence for these practical men and I use that term more or less to cover the man who was brought up on the lease and probably has very little education. In all cases the successful practical men are most resourceful, ingenious men and are really fine engineers without the technical training to go with it, but they have the engineering type of mind or they would not be successful in their work.

I think you who are turning out the young engineers possibly might weed them out a little bit more in the classroom before you turn them over to us by telling them that they have to go through this four or five years of hard life in every respect—hard work and not very attractive living or social conditions—and if they are going to give it up it is much better for them to give it up right then before they waste several years in the field.

Competition for Engineering Graduates

E. L. Grant,* Bozeman, Mont.—I am not in the petroleum engineering field. Civil engineering is my line so that I have not any specific contribution to make to the discussion. The only point I might make which would apply to all types of engineers would be that there is a very definite competition between different industries for engineering graduates. Everybody who is connected with an engineering college realizes, for instance, that the communication industry—the telephone industry—in the last 10 years has obtained a much higher quality of graduates than the railroads. The Yale transportation report that was recently issued is a very severe indictment of the general laissez faire, hard-boiled policy of the railroads toward the engineering graduates.

Apart from the problem of the specific company there is a problem of the industry itself. Is it going to get the pick or what is left, or is it going to get any? While that does not immediately affect the prosperity of the particular industry, over a long run period the getting of the best supply of administrative personnel is a very important factor and one to which many people are giving thought. The telephone companies are a great deal better off than the railroads are partly because of that one point of view.

* Montana State College.

J. M. Lovejoy.—There is another phase: In mining or railroad or almost any other branch of engineering the engineer goes out and expects to work five years without making any money. Further than that he lives usually in a camp of some kind with a whole group of other engineers, doing the same thing he is doing and making the same wages he is making, whereas in the petroleum industry he will often be isolated and be the only one of his social standing in a community living on a lease. There may not be another engineer or geologist within several miles of where he is quartered. I think that is one of the things that discourages him.

The problem of social companionship is very difficult and it is one of the things that should be explained to petroleum engineering students, and in their summer work, they, of course, should be able to see it for themselves. A mining engineer, for instance, if he goes to one of the big mining camps, leads a delightful life for five years. He may make only a small salary, but that is all right, for he has a good time and is with his friends all the time, a situation which usually does not prevail in petroleum.

Petroleum Engineering Not a Sure Road to Wealth

C. N. Gould,* Norman, Okla.—I do not know so much about petroleum engineering, but I have been watching geological students quite a few years and a good many of them have been spoiled with the idea that it is a sure road to becoming a millionaire. Unfortunately, and I think I am using the word advisedly, a few men who have graduated in geology in various schools of the United States have become multimillionaires and many young fellows think all they have to do is graduate in June, get a job in July, find a structure in August, and becomes a millionaire before Christmas. It is surprising how that idea has permeated the schools of geology, and I presume it is also true in petroleum engineering.

I want to refer to the point that Professor George brought out, that many of these young fellows, after they have graduated and gone into the field, mix up with the practical men and are really surprised to learn that there is a lot of hard, physical, grueling work in the business that they did not expect. They have not the ability to adjust themselves and get out, and we find them a few years later running hotels and conducting real estate establishments or running barber shops. It is partly the fault, I think, of the instruction that they do not get. The young men do not get the fundamental idea that it is hard, physical work and the chances are that they will not become millionaires.

H. T. Mann,† Cambridge, Mass.—I think a limited amount of experience, especially if it could be directed, is very valuable to the student in going through school, as it enables an instructor to teach the student the work much better; on the other hand, a man's best experience is gained after he gets out of school and he gains it so much faster then. I can say that from my own experience, because I started in the mining industry a number of years ago and served an apprenticeship of about four years before entering school, but felt four years after leaving school that I could have learned just about as much in one year as I did in the four years before going to school and so I felt that I lost three years.

H. C. George.—Is it not true, however, that when you went to school and when many of us went to school 20 years ago, the man went to school with a fairly definite and clear idea of what he wanted to do? Is not our educational problem much different when everybody goes to school? It is now the custom to go to school and to college, and I think we have reached much further down in the stratum of human intelligence to get our product. There is no question about that.

---

* Director, Oklahoma Geological Survey.

† Associate Professor of Petroleum Engineering, Massachusetts Institute of Technology.

H. T. Mann.—I would be inclined to differ with you on that point. I believe the men coming into the schools are of a higher grade today than they were 25 years ago. I believe that a larger percentage of the students going to school today are better prepared for the school work than was the case in our time.

Training Courses in Other Industries

W. B. Plank,* Easton, Pa.—I think you will find that the mining companies, at least some coal mining companies, have this matter of training the young college graduate well in hand. I am not suggesting that you can learn anything from them because I do not know how well you are handling the matter. Apparently the Doherty Training School has a very well worked out program, the details of which I have just seen here this morning for the first time.

The Hudson Coal Co. is one of the outstanding coal mining companies in the East and in their handling of raw college recruits they are very successful. They are very careful in recruiting their men in the first place. If they think there is any question about the man not having the stamina to stay in coal mining, at least for a two-year period, or feel at all that he may not want to go into the coal mining industry eventually, they will not hire him.

They pay him $138 per month the first year and $150 the second year. They give him a course of supervised training which is not a series of lectures and classroom assignments but a varied program in all of the various departments of their industry under close supervision. A man has direct charge of these men and checks up on them every day.

According to C. Evans,[4] the general manager of that company, there are now with his company about 50 per cent. of the men who started the course. Some classes have percentages less than that and in other classes it is higher.

The Bethlehem Steel Co. has a training course which really is not a training course but a circuit for getting acquainted with the company's plan of operation. It is of only two months' duration, and according to H. T. Morris, of that company, there are only 25 per cent. of the men who started in their courses now with the company. This percentage runs up to 42 at the end of 4 years, 41.67 at the end of 3 years, and 52.38 at the end of 2 years.

These two companies have the problem fairly well worked out.

H. C. George.—Do they have this same difficulty along social lines?

W. B. Plank.—It is peculiar, but there is no agreement as to that. Someone inquired of Mr. Morris as to what attention was paid to the social life and living conditions of the Bethlehem Steel men while undergoing the training. Mr Morris said, "We try to find them a place to live and are sure they are accomodated," but the person who inquired seemed to think that they should be made to live in the families of the men who worked in the steel mills in order to get the viewpoint of the workmen whom they will have to superintend later on. There was marked difference of opinion in that connection.

It is not necessary for all of us to go to live in the family of a steel workman or miner in order to have a sympathetic attitude toward him. In other words, we do not have to lower our social conditions in order to appreciate the conditions that he has to live under.

---

* Head, Mining Department, Lafayette College.

[4] A discussion on Student Training Courses, led by Cadwallader Evans for coal mining, and H. T. Morris for a metallurgical plant, was held during the session on Engineering Education, annual meeting A. I. M. E., Feb., 1928.

H. C. George.—However, there probably is a greater satisfaction in working for a steel company, other things being equal, because the steel company is usually operating in a community of some size and a young man can pick his society, at least he will have the opportunity to do so, whereas as Mr. Lovejoy stated, with the oil company he is thrown out where these opportunities do not exist.

Students Should Spend Summers in Oil Fields

F. J. Fohs, New York, N. Y.—Young engineers should spend each summer, after beginning their course, in the oil fields, starting with the lowest grade work and familiarizing themselves with each phase of that branch of the petroleum industry to which they expect to devote themselves. They should be advanced from phase to phase of the work only as they have proved themselves capable in the last.

More than that, a minimum of one year should elapse after they get their Bachelor's degree, this year to be spent in the field if in Production or Transportation engineering, or in a refinery or its laboratory if in Refining engineering, before admitting them to advanced studies for a Master's degree. Before a Doctor's degree is conferred, a minimum of three years' practical work should be required.

Students should be given to understand at the outset of their course that a considerable period of practical work will be necessary before they can advance to engineering and managerial positions, instead of feeling that they are ready for such positions on graduation.

I want to add to Mr. Rubel's suggestion that the young engineer expects special treatment, that he must also be willing to learn and speak the language of his associates— the untrained workers—if he is to get along and stay in his place.

I want to add to A. M. Hepler's suggestion that the social training at colleges seems to soften many of the young men to the point where their desire to meet hardships on the edges of civilization is greatly reduced; that contacts at work each summer will help overcome this.

The method proposed of giving examinations as is done in the Doherty School is helpful, but, like all methods of examination, is of doubtful ultimate value. However, I feel that the executive in charge of young engineers should not hesitate to tell a graduate after one year or more with a company, whether or not he is suited to the line of work he has undertaken. It is greater kindness to him to get him started right. Of course, this attitude should be taken also in the university by the professors, but the practical manager can soon root out men who, for one reason or another, are ill adapted to their work. Mr. Wagy has touched on this last, but I would go further and not only remove him from the work of the company, but suggest that he get into work more in keeping with his general makeup.

Small companies or organizations cannot have training schools, but the young engineer has, with proper reading, an excellent chance to get training in such companies, as he is usually called on for a greater variety of problems.

In reference to the training school, a course of required reading for each branch of work, as each branch is taken up, would be helpful. Each engineering school could furnish an up-to-date list of books for graduates. Trade journals and current scientific and Institute proceedings must also be consulted. Going back to a real school for even a four-month period, on leave of absence, would be very helpful after an engineer has been in the field. Hard continuous effort probably is more valuable than sheer brilliancy in an engineer.

The attendance once or twice a year at Institute and Association meetings, should prove helpful.

Publication of a pamphlet embodying the important suggestions of this discussion, to be summarized by Dr. George would prove of value to the aspiring young engineer.

I want to stress the increasing importance of the engineer for executive positions. Lawyer, banker and engineer are now the chief sources in the oil industry, with the engineer daily increasing in importance for such positions.

Graduate Must Take First Job Available

E. R. Lilley, New York, N. Y.—Mr. Fohs spoke on the desirability of students working in the summer time and thereby developing ideas as to what they should do after graduation. It is well to recognize that today the average student going into college is about 17 years of age. Most of the students in engineering do work in the summer time, but they are not sufficiently trained mentally to receive much help from summer work.

The student who arrives at the end of his course must have a job. There seems to be no way of definitely putting him in the job he is most fitted for. He must take the job that comes along first. I should like to see him specialize or select a line to do his work in, but the fact remains that if the business for which he is trained does not happen to be taking on men when he completes his course, he goes wherever he can secure a job. Am I right, Professor Johnson?

R. H. Johnson.—I have in mind just now that the Society for the Promotion of Engineering Education shows an amazing number of switched careers. A large number of men are not in the engineering line or in lines even broader than engineering, that they were trained for, because our personnel systems somehow or other are not functioning well, a condition due to fault partly on the company side and partly on the educational side. We are not doing a good job of it.

H. C. George.—Is it not true that many of our leading educators, along the line Mr. Fohs mentioned, claim the chief fault of our educational system is that young men are starting in higher education at the time they should be finishing it? A man should be prepared for his life work by the time he is 21 unless he is specializing in a professional course such as law or medicine.

R. H. Johnson.—Mr. Fohs hinted at the answer to that. We must look to the high school to take some of the educational vocational guidance work.

W. B. Plank.—Professor Johnson has referred to the findings of the Society for the Promotion of Engineering Education—to be exact, the composite figures for the field of work of older graduates with respect to their college course, show about 60 per cent. of our engineering graduates are following the branch for which they trained themselves in college. A smaller group of about 23 per cent. have switched to some other branch of engineering, and another still smaller group have gotten out of engineering entirely. Now, comparatively, mining engineering shows the greatest straying away. There are less than 50 per cent. of men trained in mining engineering—by that we mean all branches of the mineral industry, because it includes petroleum and mining and metallurgy—now in mining engineering, but there is a a large group, about 32 per cent., who are in other engineering branches. Then there is a group of about 16 per cent., who are in non-engineering branches. Civil engineering is on the other end of the line, for 75 per cent. of the men who took civil engineering in college are still in civil engineering. Fourteen per cent. are in other engineering branches and a small group have strayed out of engineering entirely.

There are two explanations for this. It can say it is due to the fact that the boy did not have proper vocational guidance when he went to college. That is not

the only reason. We can just as well say that the training of the mining engineer has been so broad it has enabled him to take advantage of other opportunities when they arose, not that he was forced out, but went out of his own volition. I think both of these causes operate.

Too Many Misfits—Situation Must Be Improved

J. M. Lovejoy.—Mr. George, before we change this discussion, I should like to bring it back to its more practical aspect. I want some suggestions as to how we can better take these young engineers from the colleges into the companies and develop them.

I say today that something is wrong, either the companies are wrong in the way they handle these engineers, or the educators are wrong. We lose too many men. Too many misfits come along, and, looking at it in a broad way, I think some improvement must be made. The petroleum engineering profession is very new and it needs to be built up probably more than any other branch of engineering today.

As Mr. Plank said, there are more than 13,000 civil engineering students. How many petroleum engineering students are there? Probably not half enough to go around today, and yet the companies take them in and fire most of them at the end of six months or they do not make any progress.

I should like to have any suggestions that you gentlemen can offer as to how the companies can make it a little more attractive for the young petroleum engineering graduate. We have to start him out on a par with the roustabout. He has to get the same wage and live with the roustabout and the average roustabout is a red-blooded American, as good as any. The situation is a little different from that in the steel mill, where I believe a great deal of the common labor is of the foreign element. We do not have that in the oil business, and the young chap out of college is going to rub elbows with the roustabout on an absolutely equal basis or he will not get anywhere. We have to watch him and move him around, but, as far as it has gone at the present time, that is all we have been able to do.

Chapter XIX. Graduate Courses in Petroleum Engineering

DISCUSSION

L. C. Uren,* Berkeley, Cal. (written discussion).—I heartily concur with Mr. Fohs concerning the need for advanced courses on various phases of Petroleum Engineering. I think that his criticism is probably true of most of the engineering schools that are specializing at all in Petroleum Engineering, that is, that most of their so-called graduate courses are not of graduate caliber but are merely more specialized aspects of undergraduate subjects. It would undoubtedly be to the advantage of the petroleum profession if more advanced work could be offered in a few of the leading engineering institutions so that there would be something substantial to offer graduate students wishing to return after a period of undergraduate work, for additional training. There is no doubt but that a better trained engineer, more useful to the oil industry, could be secured from schools offering such advanced training.

The problem of adpting our instruction to fit the needs of engineers trained along other lines who wish, after completion of their undergraduate work, to enter the petroleum engineering field, is a more difficult one. It has been my experience that such men are usually sadly deficient along certain lines and that they are really not prepared for the more advanced work in Petroleum Production Engineering until they have gone back over the work which they have missed in their undergraduate training.

I note that Mr. Fohs suggests that other eastern and western colleges not now stressing Petroleum Engineering, should be encouraged to take up advanced work of this character. With this, however, I cannot agree unless the institutions are also prepared to offer a full sequence of undergraduate work on which the more advanced courses may be superimposed. Whether or not there is a need for additional engineering colleges entering the petroleum engineering field is an open question. I believe that we are turning out enough petroleum engineers at the present time and that none of the six institutions now specializing in this field are overcrowded. Moreover, they are fairly well distributed over the country, though there may be room for an additional school in the field in the eastern section of the United States.

F. W. Padgett,† Norman, Okla. (written discussion).—Assuming that the student has the proper fundamentals, that is, general science and a knowledge of the technology of the industry, then the problem is: What courses should be offered from the graduate standpoint?

(*a*) *Course Work.*—His knowledge of the technology of the industry can be extended advantageously by means of one and two-hour courses, which consist in a more detailed survey of the various branches of the industry.

(*b*) *Literature.*—This work may, or may not, be connected directly with his research problem. The student should become familiar with methods of locating articles in the literature; should also become familiar with all the important original

* Professor of Petroleum Engineering, University of California.

† Professor of Refinery Engineering, University of Oklahoma.

articles pertaining to his line of work, and also learn how to abstract adequately what he reads.

(c) *Research.*—The problems are numerous and offer an important field in the line of applied science. Some men are not temperamentally fitted for research, but this will be demonstrated in connection with their research problems. If they have a talent for research they can be encouraged to pursue it further, either after becoming connected with companies or in connection with further graduate work.

Graduate Courses in Geology, Geophysics and Petroleum Engineering

R. C. Beckstrom,* Golden, Col. (written discussion).—I outline the different courses now being given as graduate work in geology, geophysics and petroleum engineering, as follows:

Stratigraphic Research

A study of individual problems in stratigraphy and related subjects, such as sedimentation, correlation and paleogeography.

Advanced Petroleum Geology

A study of the origin, accumulation or mode of occurrence of petroleum with the assembling and interpretation of data bearing on all phases of the geology of a certain oil field or petroliferous province.

Regional Geology of North America

The physiography, stratigraphy, structure and history of the geologic provinces of the continent presented by assigned reading and map study.

Geophysics for Graduate Students

Theory and Application of Magnetometers, Especially Field Balances.—The magnetic field of the earth and its different constituents are studied, followed by a comprehensive description of all types of magnetic instruments, both, for field and stationary use. The universal theory of a magnetic system which rotates about a rigid axis and has an arbitrary orientation in space is derived and its application to various types of magnetic instruments shown, especially to magnetic field balances and the instruments studied in detail. Examples of measurements thus far published are demonstrated and their interpretation discussed. Measurements in the field are made with these instruments.

Theory and Application of Torsion Balance.—A review of the behavior of the gravitational field along the earth's surface (especially of Clairaut's theorem); the theory of level planes of gravity is studied in detail. Upon these studies the theory of the Eötvos torsion balance is based and formulas for use are derived for the curvature and gradient veriometers. Special emphasis is placed upon the latter and formulas for observations in three, four and five positions are derived. The methods of determining the constants of the instruments as well as the derivation of corrections are given. Examples of torsion balance measurements are demonstrated and their interpretation discussed. As a conclusion of the theoretical part a thorough review of the development of various designs of the instrument are offered.

* Professor of Petroleum Engineering, Colorado School of Mines.

The measurements when done with the instrument in the laboratory consist of observations in different positions of the instrument and their computations. Afterwards, measurements in the field will be made in an area with sufficiently known geological structure.

Petroleum Engineering for Graduate Students

Asphalts.—A study is made of the native and pyrogenous asphalts and their use in the manufacture of the various commercial products. The student is required to make a complete review of the literature and abstract all articles bearing on the problem before the laboratory work is started. This course will ordinarily require work throughout the school year.

Lubricating Oils.—A detailed study of the factors controlling the manufacture of good lubricating oils from the various grades of crude oil and the relation of specification of their individual uses.

Filtering Clays and Decolorizing Agents Used in the Petroleum Industry.—This is essentially a laboratory course but much of the work will be done in reading and abstracting the work of others so that laboratory repetition may be avoided. The laboratory equipment such as gravity and pressure filters, contact filters with accompanying press and centrifuge are available. The different types of filters may be steam heated and if higher temperatures are desired they may be easily obtained.

Methods of Increasing Recovery from Oil Sands.—A study of the factors affecting recovery and research work covering the practical application of these to a new field or to one in which the gas pressure has greatly declined and some artificial stimulus must be resorted to.

Removal of Paraffin.—Believing this to be one of the causes of the low percentage of recovery now obtained it gives the postgraduate a wide field of investigation of a problem in which the industry is really interested. It is hoped research work along this line will assist operation in combating this ever-present obstacle to high recovery and the problem will be approached with the idea of developing some results of practical value.

Valuation.—This problem is studied from the angle of reducing it, as far as possible, to a simpler basis capable of the relatively rapid practical application usually required by the industry.

Petroleum Seminar.—This course covers articles of interest on the subjects published by the petroleum associations, trade and scientific journals.

A number of junior and senior courses are available to the men coming in from the industry. They find them instructive and a valuable review of the fundamentals and details that parallel with their field experience.

The required work given in the junior and senior year may be listed as follows: Physical Chemistry; Chemistry of Petroleum Materials; Electricity (AC) and (DC) Currents; Analytical Mechanics; Graphic Statics; Engineering Design; Petroleum Drilling; Petroleum Production; Petroleum Refining; Petroleum Engineering (construction design); Petroleum Organization and Valuation; Petroleum Thesis (problem work); Gas and Fuel Analysis; Petroleum Statistics; Contracts and Specifications; Natural Gasoline Plants; Thermodynamics; Hydraulics, and Internal Combustion Engines.

W. A. Cruse,* Pittsburgh, Pa. (written discussion).—Just as a matter of information I am prompted to say that I am in entire sympathy with encouraging graduate work in petroleum topics; I have always felt, however, that graduate work is largely a personal matter depending on the abilities and interests of the teachers and investi-

* Senior Industrial Fellow, Mellon Institute

gators. It is my impression that the supply of such men who have any experience in petroleum topics is rather inadequate for the installing of any large number of graduate courses on the subject. It would therefore seem that at present the proper procedure would be to give a year or two to publicity, agitation and encouragement in order that suitable teachers would have time to acquaint themselves with the subject. After such a period the listing of graduate courses in petroleum might be undertaken with more success.

With regard to the second point mentioned by Mr. Fohs, that of providing graduate courses in petroleum engineering for mature geologists and mining engineers who desire to enter petroleum engineering, it seems to me that what is wanted here is not so much graduate courses as adequate and thorough upper class undergraduate courses. My impression is that men who have the training of geologists and mining engineers have already learned to think; what they desire, therefore, is specific information and this can be supplied to them rapidly and conveniently by University course work. This course work is presumably of about the caliber that should be supplied to advanced undergraduate students on the subject mentioned.

Graduate Courses in Petroleum Engineering

H. C. Fowler,* Washington, D. C. (written discussion).—Mr. Fohs has presented two points for consideration in relation to graduate courses in petroleum engineering: (1) Adequate studies to augment the four-year curriculum of colleges now having departments of electrical, mechanical, civil, and mining engineering; (2) graduate courses for geologists and mining engineers, turning to the petroleum industry for employment, in colleges that do not now stress petroleum engineering. In addition, the relatively small group of engineering colleges which have developed comprehensive four-year courses in petroleum engineering should be mentioned, although they are an amplification of the first group referred to by Mr. Fohs.

In considering graduate courses for petroleum engineers, recognition should be made of two related but distinct groups of students; those who naturally will follow the trend of exploration, development, and production—commonly designated as petroleum engineering subjects; and those who are more interested in refining processes—the second division coming under the designation of refinery engineers and petroleum chemists. Undergraduate courses which a student elects to follow at the beginning of his four-year course will have considerable bearing on what his postgraduate work will be.

The following observations are confined to courses which I think have value to the embryo engineer whose natural inclinations will take him eventually into the field rather than to the refinery. But discussion should not be confined to this group. Many points applicable to field engineers are just as important to refinery engineers and chemists. The men who return to college after they have been at work in industry for a number of years represent a distinct group and present certain problems not met in the other groups of fifth year students.

To aid in suggesting suitable postgraduate courses, the place of the petroleum engineer in industry should be considered first. A. C. Rubel, petroleum engineer, Union Oil Co. of California, has presented this subject admirably in his paper delivered at the Chicago meeting of the American Petroleum Institute.[5] Rubel says, "He (the petroleum engineer) is essentially a translator to the operating and executive members of the industry, capable of assembling technical and scientific principles

---

* Petroleum Engineer, U. S. Bureau of Mines.

[5] A. C. Rubel: Advent and Place of the Development and Production Engineer in the Oil Industry. A. P. I. *Bull.* (Dec. 7, 1927).

into practical, workable form for the help and guidance of executives and field operators, and conversely of analyzing field problems into technical form for scrutiny and solution."

"Background" Needed by Young Graduate

A. W. Ambrose[6] voiced this growing need for men trained in the technique of petroleum engineering some years ago, when he wrote: "His duties are to apply his scientific and geological training practically to oil field development. He should be by education a mining, civil or mechanical engineer, with a working knowledge of geology and chemistry."

It is hardly to be expected that a young graduate will fill all the requirements of a petroleum engineer upon entering into duty in commercial life. The engineer's place in the petroleum industry has been one of slow growth because he has had to develop and acquire experience that will serve best the needs of the industry. Therefore, the industry cannot ask the young graduate to leave college completely equipped. He needs "background" and that is what the fifth year in college should offer in so far as possible.

Background is of two kinds: That acquired by personal contact with men and conditions, and that gained by thorough training in the fundamentals of science and learning. Personal contact comes largely after the college course is completed; although some schools are now giving opportunities of this nature which were not possible a few years ago.

The second condition, then, should be the chief aim of the graduate course. How can the alma mater help most to implant fundamental ideas in the minds of her sons, thereby enabling them to go out and become "translators . . . capable of assembling technical and scientific principles into practical, workable form," and of analyzing field problems?

A mistake many young graduate engineers make upon going out into industry is to feel the importance of their position. This is but natural and in some ways may be beneficial. It lends assurance of accomplishment. But would it not be better for them and the company into whose employ they go, if this assurance were reinforced with a few more girts and sway braces, or built upon a better foundation?

During the four undergraduate years, we must assume that the student has successfully mastered various prescribed courses of applied mathematics and mechanics of materials; has been given some instruction in the elements of geology and chemistry; and his knowledge of the working of certain known physical laws has been broadened considerably.

What will make his fifth year in school more valuable to him, and to the industry which he will later serve, than "postgraduating" in the field? The fifth year courses should be of such a nature that they will justify the time and money spent in acquiring helpful knowledge. The engineering degree conferred should be secondary in importance. The fifth year graduate should be a better "translator" of technical and scientific principles than a four-year student who has spent one year in the field. Therefore, courses directed to that end should not only implant the fundamental axioms of sciences, but they should round out the four years with training in scientific thinking as well as "figuring."

If the fifth year can teach the young engineer (1) where to find data, (2) how to compile records, (3) how to analyze them, and (4) how to express the results, the year will have been spent profitably. The ability to gather correct and sufficient data pertaining to any subject is essential to the engineer. Data are of many kinds;

---

[6] A. W. Ambrose: Underground Conditions in Oil Fields. Bur. Mines *Bull.* 195, (1921).

those of a statistical nature should be augmented by explanatory notes and references, for often mere figures mean little unless the conditions under which they are obtained are known definitely. "Buy a handbook and learn how to use it" is the statement made by a professor of civil engineering to his class. But this advice while timely does not go far enough. Handbooks are useful but many data pertaining to a developing science are not found in handbooks. The student should be given extensive reading courses. Acquaintance with sources of information in reference books and current periodicals will broaden his view. The young engineer should card-index his reading material. He should also be given some training in determining when it is advisable to collect data from his own observations.

Records form a large part of the material with which engineers work. Yet how much instruction do most students receive in the art of keeping records? If the engineer is to translate and interpret, he must know how to collect and arrange his "stock in trade" and to differentiate between valuable material and extraneous matter. A course should be given, directed to this end in which the student learns to gather and assemble data by working on definite problems.

The ability to analyze data is the background of fundamental thinking to which emphasis should be given in the fifth year. Together with this instruction and training, the student should have a course or courses that will organize in orderly fashion the mathematics of undergraduate years. One successful engineer has said, "Give me a young man who has been properly schooled in the science of physics so that he grasps the reasoning applied to physical laws, and I shall not worry about the rest of his engineering training."

The fifth year should include not only a review of applied mathematics but an advanced course in applied physics—linking it up with general problems which will be met in the field. However, it does not follow necessarily that the laboratory has to be made over into a miniature oilfield to accomplish the desired results. The ability to reason and visualize should come first; its application will be found later in the large scale laboratory of actual practice.

One of the greatest handicaps that the young engineer has to meet is his inability to express himself simply and to the point. Many letters and reports, written by engineers, fail to tell what they should because of their vague and cumbersome presentation. If the student can be taught that much of his success in later years will depend upon reports which he will submit to his chief, the aversion to English courses and even to oral expression will be overcome in large measure. The ordinarily prescribed course in "freshman English" neither appeals to nor fulfills the requirements for most engineering students. If in the fifth year, a course is given in technical English and report writing, which includes some instruction in the preparation of business letters, a helpful part of the "background" will have been established.

Elective courses are few in an engineering school, due to the necessity of covering many prescribed courses; but somewhere within the fifth year, the economic phase of engineering should be stressed. Rubel says: "Unfortunately, the average petroleum engineer . . . understands but little . . . about the economic effects of developments." Does this not point directly back to incomplete ground work? The line of thought or reasoning needs direction, and at least an impetus in this direction of the economic phase of petroleum engineering should be given in the fifth year work.

Other subjects might be considered, but the fifth year should not be so crammed with various subjects that the student will gain no lasting benefit from any of them. To maintain interest and to give the student a picture of what industry is doing, his reference work should be supplemented at frequent intervals by informal lectures. These should be given by engineers who are active in various branches of the industry and who from experience know the value of thorough training in the fundamental sciences.

Teach the student to think in engineering terms, how to weigh and analyze data, and how to present his facts to others, and you have given him an enviable background, from which to start him toward becoming a petroleum engineer.

I have said nothing so far about the geologists and mining engineers who return to college to prepare themselves for entering the petroleum industry except that they represent a distinct group. Up to the present time it is a relatively small one but one likely to grow in size. There are two courses open to men in these professions; either to apply their past experience directly to the "business of oil" and take their postgraduate work in the field; or to take such courses in college that will place them in a better position to stand on even ground with engineers who have spent some years in the petroleum industry.

The engineer returning to the university after several years in the field as a geologist or mining engineer will have an experience background not yet approached by fifth year students. No doubt some of the fifth year courses will be helpful to the returning engineer; especially advanced courses in applied physics; but what this type of older graduate student needs most is an opportunity to adjust his learning to fit methods of operation different from those to which he has been accustomed. Personally, I think that the best place to do this is in the employ of a company. But such an arrangement is not always possible, and the man of several years' experience often hesitates to accept a position which is likely to place him in a subordinate position while he is learning a new game.

For such men, special problems in petroleum technology should prove of greater benefit than the more academic courses offered to younger engineering students. This work should allow ample time for extensive reading, and frequent conferences should be arranged with instructors.

Graduate study of this nature should be undertaken at a school where a course in petroleum engineering has been developed. At such a school, the returning engineer is more likely to find advanced courses in line with actual field conditions. Schools that do not maintain a department of petroleum engineering are not equipped to give proper advanced courses to geologists and mining engineers; and in turn, these men usually will not look to this type of school for help in becoming petroleum engineers.

R. H. Johnson.—In general it should be the purpose of our schools to turn our students over to industry at the end of the undergraduate course. Moreover, they should have had a summer's field work under instructors, and at least one summer of company work, not under instructors, by that time. This is because (1) the industry needs more men than can be carried through graduate courses, and (2) it is socially unwise to hold young men out of self-support longer than important to do so. Yet we need graduate courses for two classes, first, those who decide too late to take up this field to permit covering the curriculum in the four years, second, for the intensive training of specialists. However, men who have in mind a specialty should start shaping their course to that end in their undergraduate years to reduce the time necessary as graduate students.

Oil Company Engineers as Training Talent

F. J. Fohs.—I especially commend the written discussions by Messrs. Beckstrom, Uren and Fowler. Mr. Beckstrom's list of graduate courses is helpful, but a fuller discussion of what subjects should be included is desirable.

We have enough undergraduate schools of Petroleum Engineering, but especially in the East, at centers like New York, Chicago and Philadelphia, advantage might be taken by engineering schools of the engineers connected with the home offices

of large oil companies and refineries and press such men into service to aid in training engineers who want to specialize in petroleum after they already have a good engineering foundation; also to aid those connected, in subordinate capacities, with such companies, to advance.

I do not think each University need offer the same graduate courses. Some will be better fitted through instructors and environment for certain courses than for others.

In addition to lectures by the Engineering Professor of a University, and the special lectures, courses in reading best adapted for each student should be stressed and I think should be given a greater weighting than the lectures in determining the results attained by a student. The lectures are chiefly intended to inspire, whereas the reading is to give background in self-study to an engineer who, once in the field, must largely rely on himself in the study and solution of problems.

INDEX

(NOTE: In this index the names of authors of papers and discussions and of men referred to are printed in SMALL CAPITALS, and the titles of papers in *italics*.)

D

E

N

R

S